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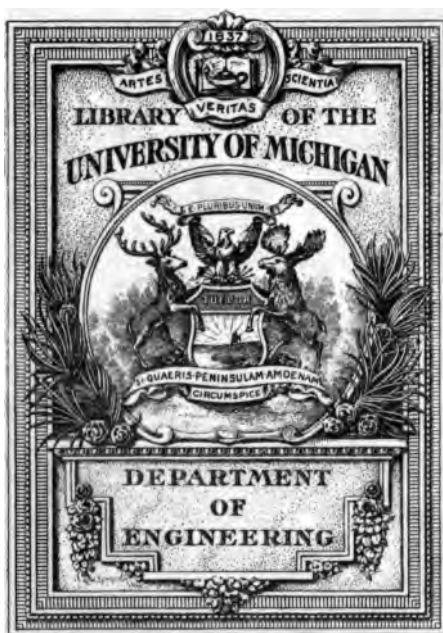
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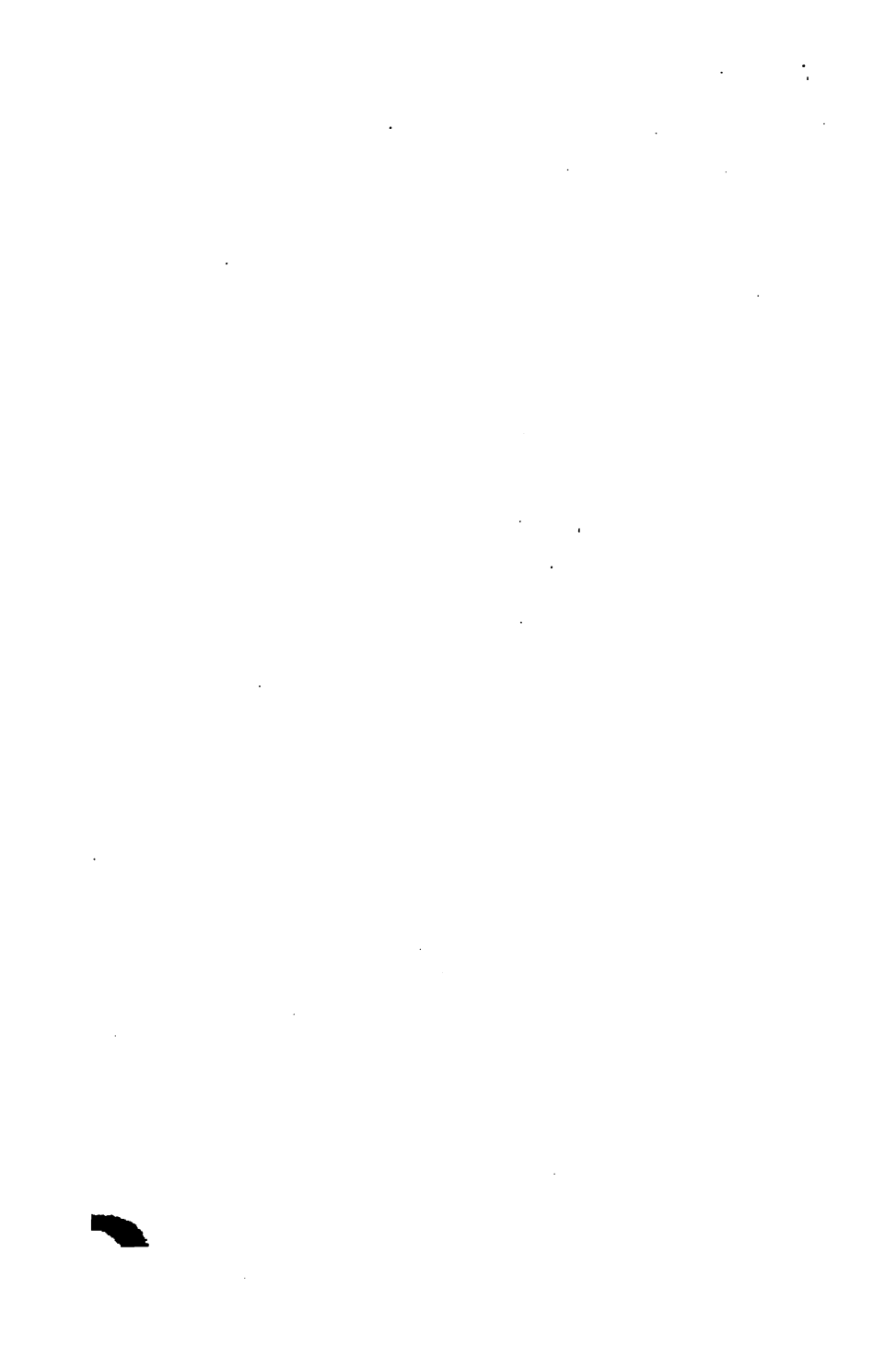
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Furnace Efficiency

Combustion and Flue Gases

BY

JAMES C. PEEBLES, M. M. E.

CHICAGO

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1914.

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PREFACE

Coal is the great source of energy from which is derived by far the greatest part of the mechanical and electrical power now used in the industrial world. From the beginning of civilization man has made use of this great source of energy apparently with the idea that it is an inexhaustible supply. But unfortunately the coal supply is not unlimited and the time must come when it will be exhausted. What we will do for power when that time arrives is a problem for future generations to solve.

The problem for the present generation to consider is the economical use of our available coal supply, so that the time when the coal will be exhausted may be postponed as long as possible. There is perhaps no class of men so intimately in touch with the problem of the conservation of our coal supply as the operators of steam power plants. A vast amount of coal is consumed every year in the power plants of the world and power plant operators should be able to do much towards the solution of this important problem.

It is the chief engineer, the man in responsible charge of the power plant, to whom we must look for economy in the use of fuel. He should be familiar with the latest and best work that has been done on the problem of combustion, and should instruct his firemen and others in his plant how to operate the furnaces at highest economy.

The purpose of the author in preparing this book has been to set forth in convenient form and in as non-technical language as possible the efforts that are now being made to increase the efficiency of coal combustion in the

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steam boiler furnace. It should be of special interest to all chief engineers of steam power plants, but it is believed that every man having anything to do with the power plant, from manager or superintendent to fireman, will find something of interest and value in its pages.

Competition in all lines of business has now become so keen that all waste and inefficiency must be reduced to the absolute minimum. The power plant operator can no longer waste fuel without being called to account, and hence the chief engineer must keep up with the times in matters of combustion or he may find himself displaced by a more up-to-date man. It is believed that this book will make clear to the engineer how he can operate his particular plant at maximum efficiency as regards the boiler room.

The thanks of the author are hereby extended to the various manufacturers of furnace equipment who have very kindly supplied many of the illustrations used. He is particularly indebted to the engineers of the Green Engineering Company for many helpful suggestions. Obligation must also be acknowledged to Mr. Joseph W. Hays and Mr. Joseph G. Branch, to the writings of the former for certain data and illustrations, and to the latter for many helpful criticisms and suggestions.

THE AUTHOR.

Chicago, May, 1914.

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Furnace Efficiency

CHAPTER I.

In practically all steam-power plants the largest single item of operating expense is the coal bill. If we wish to run the plant economically it would seem to be reasonable to try to save money where we spend the most of it. But the history of operating engineering practice in the steam plant shows that this has not been the case, at least not until very recently. The engineer will spend much time and thought on his engine, putting it in the best possible condition for efficient operation; this is perfectly proper and is a mark of the progressive engineer. Too often, however, his efforts at increased efficiency and economy stop with the engine, in spite of the fact that in the average plant dollars can be saved in the furnace room where dimes are saved at the engine.

It has been said that necessity is the mother of invention, and it is equally true that competition is the mother of economy and efficiency. The operating engineer is just beginning to feel the competition of the big power and light companies, and that competition is going to become keener as time goes on. It is no exaggeration to say that the central-station solicitor is after the engineer's job, and he will get it if he can show the boss that the big company will furnish him with power cheaper than he can generate it in his own plant. On the other hand, if the operating engineer is progressive and up to the minute on all

points affecting economy and efficiency of operation, in most cases he will be able to show the power-plant owner a set of figures on power cost which the central-station man is unable to meet. It's all a question of the most power for the least money, and unless the operating engineer in the small plant can generate power for a little less money than the central station will supply it, his plant will be shut down and he will be out of a job.

It is our purpose here to discuss some of the problems which arise in the furnace room and which are vital to the economical operation of the plant. In the past too little attention has been given to furnace operation, with the result that in the average plant large fuel waste has become the rule rather than the exception. The statement that the majority of steam plants waste 10 per cent of the coal used is probably not far from the truth, while many "terrible examples" exist where as much as 40 per cent of the fuel is wasted. Wouldn't it be worth while to reduce your coal bill 10 per cent or more? It would make you "solid" with the boss, and the central-station solicitor wouldn't call the second time.

The function of a boiler furnace is to transform the heat energy of the coal into a form available to the boiler, and to deliver it in that form with the least possible loss. The function of the boiler is to use this energy in the generation of steam. Thus the furnace and the boiler have different functions to perform, and in all of our efforts toward economy of operation we must recognize this fact. The efficiency of the furnace is perhaps more influenced by the manner of its handling than is the case with the boiler, and for that reason the furnace offers the more fruitful field for effort toward greater efficiency through increased care in operation. We shall therefore devote the greater part of our attention to the furnace.

In the first place, if we wish to improve furnace efficiency and so get more steam with less coal, we must have some standard by which to judge the furnace. In other words, we must be able to recognize an efficient furnace when we see it. Most engineers would say that an evaporative test is the best guide to furnace efficiency, but this is not the case, because the evaporative test depends upon both boiler and furnace and is the measure of their **combined** efficiency, while for the present, at least, we are interested only in the furnace. A boiler in bad condition, covered with soot and lined on the inside with scale, might give a low evaporation even when furnace efficiency was reasonably good. Thus the evaporative test is not the rule by which to measure furnace efficiency.

One prominent engineer has defined an efficient boiler furnace as one which **completely consumes the combustible in the fuel with least possible excess of air**. This is the proper test to apply to the furnace, and the only one which tells us all we need to know about it. It is not our purpose in this connection to enter into a discussion of the theory of the combustion process. A knowledge of the chemistry of combustion may be desirable from an academic point of view, but it doesn't require a chemist to operate a boiler furnace efficiently any more than it requires an expert in thermodynamics to run a steam engine.

The important question is: Are we burning all the combustible in the fuel with just as small an excess of air as possible? To answer this question we must be able to analyze the gases of combustion coming from the furnace. The practical engineer should not become discouraged at the use of the word "analyze." There is nothing about boiler-flue-gas analysis which any engineer can not understand; in fact, he can even instruct his fireman how to make the analyses.

Every engineer knows that the chief combustible part of coal is carbon. The burning of coal in the furnace is practically nothing more than the combining of this carbon with the oxygen of the air. Air is only about 21 per cent oxygen, the remaining 79 per cent being mostly nitrogen, which takes no part in the burning. The function of the nitrogen in the air is merely to dilute the oxygen. When carbon unites with oxygen it forms a gas, called carbon dioxid, represented by the symbol CO_2 , which means one part of carbon and two parts of oxygen. This carbon dioxid will therefore be present in the gases coming from the furnace, and it is the **amount of this CO_2** in which we are chiefly interested in the flue-gas analysis.

If all the 21 per cent of oxygen which the air contains were to be consumed in the furnace and turned into CO_2 , then the products of combustion coming from the fire would contain just 21 per cent of this gas. That is, if just the proper amount of air were supplied and if all the combustible in the coal were consumed, the flue gases would contain 21 per cent of CO_2 . But in actual practice it is never possible to realize this ideal condition, due chiefly to the fact that the oxygen of the air can not be brought into close enough contact with all of the combustible of the fuel to produce complete combustion unless there is some extra air present. The result is that in all boiler-furnace practice an excess of air is always allowed to pass into the furnace, so as to make sure that all of the combustible in the fuel will be burned. An excess of 40 per cent to 50 per cent represents good practice, but many times it runs up to 100 per cent, 200 per cent, and even higher. Suppose that 100 per cent excess air is being used; this means that just **twice** as much air is passing into the furnace as is needed under ideal conditions to completely burn the fuel.

Under these conditions the gases coming from the furnace will contain only half as much CO_2 as before, because one-half of the air is passing through the furnace unchanged. That is, the CO_2 will now be only $10\frac{1}{2}$ per cent instead of 21 per cent. Joseph W. Hays, a well-known expert on combustion engineering, illustrates this point as follows: Suppose that a quart of milk contains 21 per cent of cream; now if we add one quart of water to the milk we shall have no more cream than before, but we shall have two quarts of "near" milk. Therefore, the cream is now only $10\frac{1}{2}$ per cent of the whole, or just one-half of what it was before.

The point that must be clearly understood here is that the percentage of CO_2 in the flue gases is a direct index of the amount of excess air which is passing through the furnace. Suppose that the flue gas shows 7 per cent CO_2 ; the percentage of excess air under these conditions may be calculated as follows:

$$\frac{21 - 7}{7} \times 100 = 200 \text{ per cent excess.}$$

Subtract the observed percentage of CO_2 from 21; divide this remainder by the percentage of CO_2 ; multiply this result by 100. Thus the flue gas analysis provides a convenient method for measuring the efficiency of the furnace, because, as we have seen, the efficient furnace is one which consumes the combustible in the fuel with the least possible excess of air.

Let us examine this definition of an efficient furnace and see, if possible, **why** excess air reduces furnace efficiency. A brief study of the chemistry of the combustion process shows that it requires about $10\frac{1}{2}$ pounds of air to burn 1 pound of coal. Of course, this differs somewhat with different coals, but $10\frac{1}{2}$

pounds is a fair average figure. If in addition we allow for an excess of, say, 50 per cent, there will be $15\frac{3}{4}$ pounds of air passing through the furnace for every pound of coal thrown onto the grate. This excess air, $5\frac{1}{4}$ pounds per pound of fuel, passes through the furnace and up the smokestack unchanged, **except in one important particular. Its temperature has been raised.** The average yearly temperature of the air entering the furnace is probably not far from 60° F., while the temperature of the flue gases in uptake or breeching is about 500° F. or more. Hence this excess air, which hasn't helped the combustion any, and has done no useful work, has had its temperature raised at least 440° F., **and this takes heat.** When the air excess is 50 per cent, as assumed above, it takes approximately 13 per cent of the total heat in the fuel to heat up this air, together with the nitrogen contained in the air actually used. The writer has tested boiler furnaces which showed CO_2 as low as 3 per cent; this means about 600 per cent excess air, with a loss of approximately 75 per cent of all the heat in the fuel. A furnace operated in such a manner has no place in a steam plant; it is really a hot-air heating plant for all outdoors.

One point to be kept in mind in connection with heat losses through excess air is the fact that as the percentage of CO_2 in the flue gases goes down, the heat loss goes up, but not proportionally. Suppose, for example, that a test shows 12 per cent CO_2 ; this means about 75 per cent excess air, and will cause a loss of about $17\frac{1}{2}$ per cent of the fuel. Now if the CO_2 be raised to 13 per cent, the air excess becomes about 61.5 per cent and the heat loss 16 per cent. Thus a gain of 1 per cent in CO_2 causes a saving of $1\frac{1}{2}$ per cent in the fuel. On the other hand, take the case of 3 per cent CO_2 cited above; this means 600 per cent excess air and a loss of at least 75 per

cent of the total heat of the fuel. Now if the CO_2 can be increased to 4 per cent, we shall have an air excess of 425 per cent and a heat loss of about 58 per cent. Thus an increase of 1 per cent in CO_2 means a saving in heat of approximately 17 per cent. So the value of 1 per cent of CO_2 depends very largely upon where it is. When it is as low as 3 per cent or 4 per cent, any earnest effort to decrease air excess is almost sure to result in increased economy, while if CO_2 is in the neighborhood of 12 per cent to 14 per cent, large increase in economy is not possible.

Volumes of hot air escaping at the top of the smokestack can not be detected by the eye, and for this reason the question of air excess has received much less attention at the hands of the engineer than it deserves. All other furnace losses are practically sure to be small compared with this one, and yet it is the last one to receive attention. If the power-plant owner, or any one else in authority, should happen to discover a large amount of unburned coal in the ashes from the plant, the engineer would be very likely to receive a call from the office and be asked to explain why he is wasting fuel. Now it may be that the engineer is a thoroughly competent man and is operating his plant at maximum efficiency, but the boss can see that coal in the ashes, and it looks like poor economy to him. But let us consider a minute and we may see that the man in the plant is a better engineer than the man in the office. One of the most fruitful sources of excess air is holes in the fire; if the fire burns through in spots vast quantities of cold air rush through the holes and furnace efficiency is seriously impaired. To prevent holes in the fire it is often necessary to carry a slightly thicker bed of fuel on the grates than would otherwise be necessary. This is particularly true of the chain-grate stoker, which is coming into such general use. The fuel bed

must be thick enough to prevent the fire from burning off at the back of the grate. It is good economy to do this even at the expense of running some unburned coal off the end of the grate into the ash pit. As much as 50 per cent combustible in the ash may be more economical and an evidence of better operating engineering than an ash pit which shows no combustible at all.

Questions and Answers.

Q. What is the function of a boiler furnace?

A. To transform the heat energy of the coal into a form available to the boiler.

Q. What is the function of the steam boiler?

A. To take the heat from the furnace and use it in the generation of steam.

Q. Is the evaporative test a good one to determine furnace efficiency?

A. No.

Q. Why not?

A. Because evaporation depends upon both furnace and boiler, and is a measure of their combined efficiency.

Q. How may we define an efficient furnace?

A. An efficient furnace is one which consumes all the combustible in the fuel with the least possible excess of air.

Q. How can we tell how much excess air a furnace is getting?

A. By an analysis of the gases coming from the fire.

Q. What is the chief combustible part of coal?

A. Carbon.

Q. In the combustion process, what becomes of this carbon?

A. It unites with the oxygen of the air to form carbon dioxid, CO_2 .

Q. What is the maximum amount of CO_2 that it is possible to have in the boiler furnace gases?

A. 21 per cent.

Q. Is this ever realized in practice?

A. No; excess air is always used, and this reduces the percentage of CO_2 .

Q. What is the effect of excess air on furnace efficiency?

A. It reduces the efficiency.

Q. Why is this?

A. Because of the large amount of heat required to heat the excess air.

Q. How can the percentage of excess air be calculated from the CO_2 in the flue gases?

A. Subtract the percentage of CO_2 from 21; divide the remainder by the percentage of CO_2 ; multiply this result by 100.

Q. What percentage of CO_2 represents good practice?

A. From 12 per cent to 14 per cent.

Q. Why is excess air such a common cause of low furnace efficiency?

A. Because it can not be seen, and its effect is therefore not readily realized.

Q. How much heat is lost in this way?

A. From 12 per cent to 75 per cent of the total heat in the fuel.

Q. Does unburned coal in the ashes mean as large a loss as excess air?

A. No; 50 per cent combustible in the ash may be more economical than holes in the fire, which cause large excess of air.

CHAPTER II.

It has been shown that the only reliable index of furnace efficiency, as distinguished from combined furnace and boiler efficiency, is to be found in the flue-gas analysis. The question of how to make this analysis is therefore one of importance, and should be understood by every engineer.

Perhaps the best known and most widely used equipment on the market for this purpose is the Orsat gas-analysis apparatus, as shown in Fig. 1. As usually made, this apparatus is designed to test for carbon dioxid (CO_2), oxygen and carbon monoxid (CO). The essential parts of the apparatus are the three U-shaped bottles, A, B and C; the measuring burette D, and the leveling bottle E. It will be seen from the figure that the bottles A, B and C really consist of two bottles each, connected at the bottom with a bent tube of glass. Also it will be noted that the bottle on one side is closed with a rubber stopper, through which a small glass tube passes to act as an air vent, while the other bottle has a long glass stem provided with a plug cock of ground glass. The measuring burette is provided with a scale, reading in cubic centimeters, the capacity of the burette being 100 cu. cms. The zero of the scale is at the bottom, where it will be seen that the burette is made of comparatively small diameter, so as to give a more open scale. At its top the burette D is drawn down into a small tube and connected with a piece of rubber tubing H to the glass header F, G. This header is a tube of very small bore, so that its capacity is negligible as compared with that of the measuring burette D.

The leveling bottle E is connected with a rubber tube to the bottom of the burette D. This is for the purpose of drawing flue gas into the measuring bu-

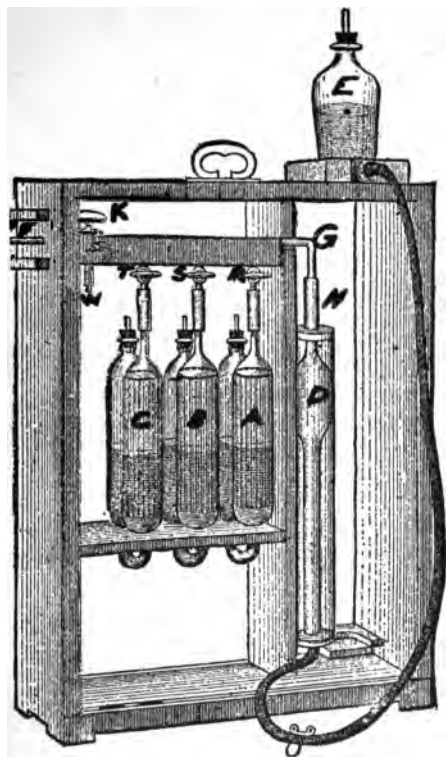


FIG. 1.

rette and expelling it again, which is done by lowering or raising the leveling bottle. Each of the U-shaped treating bottles, A, B and C, is connected to the glass

header F, G, so that they may be connected to the source of gas supply at F or to the measuring burette D as may be desired.

The treating bottle A contains a solution of caustic potash, which removes the CO_2 from the flue gas. Bottle B contains a solution of potassium pyrogallate, which removes the free oxygen from the gas, and bottle C contains a saturated solution of cuprous chlorid for removing CO. These chemicals may be obtained at any chemical supply house, and at most drug stores. The solutions may be prepared as follows:

The caustic potash solution may be prepared by dissolving one pound of commercial caustic potash in 1,000 c. c. of water. Considerable heat is evolved when the potash is dissolved in the water, and for that reason the bottle should be placed where no damage will be done if it should break. Care should be taken to keep the potash solution from coming into contact with the hands or the clothing. It is a powerful alkali, which is extremely unpleasant when it gets on the hands, and will destroy the clothing almost as quickly as an acid. When the solution is cold it should be put into a stock bottle, which can be drawn on from time to time as needed.

To make the potassium pyrogallate, take 100 c. c. of the potash solution already prepared and add to it five grams of pyrogalllic acid. This acid comes in the form of a white powder, which dissolves readily in the potash solution. After a little experience it will not be necessary to weigh the five grams of pyrogalllic acid, as the proper amount can be estimated with sufficient accuracy by simply pouring it into the palm of the hand. It must be remembered that this "pyro" solution has a strong affinity for oxygen, and hence it must be kept away from the air in a stoppered bottle.

The cuprous chlorid solution for removing the CO is the most difficult of all the reagents to prepare, and

is, perhaps, the most unsatisfactory in its action. First prepare about two liters of dilute hydrochloric acid, specific gravity 1.10, by diluting muriatic acid with an equal volume of water. Then select a large bottle of at least two liters capacity and cover the bottom about $\frac{1}{2}$ inch deep with copper oxid. Then add a number of pieces of copper wire long enough to reach from the bottom to the top of the bottle. These wires should make a bundle about an inch in diameter. Now fill the bottle with the dilute hydrochloric acid and wait for the copper to dissolve in the acid. Shake the bottle occasionally, to keep the contents well mixed. When the solution has become colorless, or nearly so, it should be poured into a smaller stock bottle ready for use. This stock bottle should contain some pieces of copper wire to keep the solution saturated. Many chemical supply houses keep this cuprous chlorid solution in stock, and the average user will probably find it more satisfactory to buy the solution already prepared, when possible. It must be protected from both air and sunlight, which cause it to become weak and turn dark.

All the reagents having been prepared, the apparatus can now be made ready for the flue-gas test. Pour the caustic potash into treating bottle A until the solution stands about half way up in both limbs of the bottle. Pour bottles B and C half full with "pyro" and cuprous chlorid respectively. We must now bring the solutions in the front limb of the treating bottles to exactly the same level. The proper level is indicated by a mark on the glass stem at the top of the bottle. The bore of the stem at this point is very small, so that a slight inaccuracy in the level of the solution will not cause any appreciable error. Suppose that we wish to raise the solution in the front limb of bottle A to the mark on the glass stem. Open the valve K in the header F, G and raise the

leveling bottle E. This will fill the measuring burette D with water, the air which it contains being forced out at F. Now close the valve K and open the one over bottle A, marked R. Lower the leveling bottle E, causing the water level to fall in burette D. This will reduce the pressure over the solution in the front limb of bottle A and the liquid will rise there, and fall in the rear limb. Continue to lower the leveling bottle until the solution reaches the mark on the stem, and then close valve R. In the same way the solutions in the other treating bottles should be brought to the proper level. The apparatus is now ready to make the analysis.

Slip a piece of rubber tubing over the end of the glass tube at F and connect the free end of the tube to the pipe which is to supply the flue gas. A pinch cock on this rubber tube will be of service. The three-way cock K should then be opened, while cocks R, S and T are closed. Raise the leveling bottle E, thus filling the burette D with water and forcing all the air out at W. Raise the leveling bottle until water reaches the point G, but do not force any of it out at W. Now turn the three-way cock K so as to open up to the pipe from the flue connected at F. The outlet at W will then be closed. Lower the bottle E and thus draw in a charge of gas from the flue. Continue to lower the leveling bottle until the water in the measuring burette D falls **below** the level of the zero on the scale. Now place the pinch cock on the rubber tube connected at F, thus closing the connection to the flue. Open cock K to the atmosphere and slowly raise the leveling bottle E until the water in burette D reaches the zero on the scale. This will force a small amount of gas out at W, and we shall have left just 100 c. c. **under atmospheric pressure**. Close the three-way cock K.

Thus far our attention has been confined to getting

a sample of gas for analysis. We shall now proceed with the analysis itself. Open the cock R, raise the leveling bottle E, and thus force the gas sample out of the burette D and into the treating bottle A containing the caustic potash solution. The potash will be forced almost entirely out of the front limb of the bottle and into the rear one. In most forms of the Orsat apparatus the front limb of the treating bottle is filled with a bundle of small glass tubes. These tubes become wet with the chemical and offer a large surface for absorption of the gas. Allow the gas to remain in treating bottle A for about a half minute, then lower the leveling bottle and draw the gas back into the measuring burette. This will cause the solution to rise again in the front limb of bottle A and wet the small glass tubes on the inside with fresh potash. Then force the gas back again into A and repeat the operation several times. In order to get a complete absorption of CO_2 the gas must be kept well agitated, which can be accomplished by passing the gas frequently between the burette and the treating bottle.

When it is thought that the CO_2 has been all absorbed, pass the gas back into D, lowering E until the solution in A rises to the mark on the stem where it was before. Close cock R. Now bring the surface of the water in E to the same level as that in D. This can be done by sighting across the surface of the water in E and is for the purpose of insuring normal atmospheric pressure on the gas remaining in D. It will be noted that there is less gas than before, the water level now standing **above** the zero of the scale. If the water level stands at 10 on the scale it means that 10 c. c. of CO_2 has been absorbed, which is 10 per cent of the total 100 c. c., with which we started. The gas may now be passed into bottle A again, and if when it is returned to D the water level still stands

at 10 on the scale, one may be sure that all the CO_2 is absorbed.

The remaining gas is next passed into bottle B, where the free oxygen is absorbed. The procedure is exactly the same as for CO_2 . Suppose that after all the oxygen has been absorbed the scale reads 19.5 per cent. This means that CO_2 plus oxygen equals 19.5 per cent; but since the CO_2 has already been shown to be 10 per cent, it leaves 9.5 per cent for oxygen.

Next pass the gas into bottle C, where the CO is absorbed. This gas is usually present in flue gases, in very small quantities, if at all, and its determination must be made with care to insure accuracy. The method is exactly the same as for the other gases. If the reading on the scale after the CO has been absorbed is $20\frac{1}{4}$ per cent, the amount of CO is evidently $20\frac{1}{4} - 19\frac{1}{2} = \frac{3}{4}$ per cent, the $19\frac{1}{2}$ per cent being the sum of CO_2 and oxygen already determined.

The chemical reagents used with the Orsat apparatus will wear out after a time and must be replaced. The caustic potash solution will absorb about forty times its volume of CO_2 . If the treating bottle A contains 100 c. c. of the potash, it will dissolve $40 \times 100 = 4,000$ c. c. of CO_2 . If the average amount of CO_2 in the flue gas were 10 per cent, that is, 10 c. c. to every 100 c. c. of gas, then the caustic potash would be good for about four hundred tests.

The capacity of the potassium pyrogallate solution to absorb oxygen is much less, 1 c. c. of the "pyro" being able to absorb only 2 c. c. of oxygen. If we assume again 10 per cent CO_2 and about 10 per cent of oxygen as the average, then the potassium pyrogallate must be replaced after twenty tests.

The cuprous chlorid will absorb only its own volume of CO, but since the CO is present in flue gas in such small quantities the solution is good for a large number of tests, provided it is not exposed to air and

sunlight. It is well not to work the solutions to the limit, but to replace them when they begin to grow weak. Weakness of the solutions will be indicated by an increasing amount of time required to complete the absorption of the various gases.

One very important point in flue-gas analysis is the obtaining of a sample for test which shall be a fair average of all the gas in the flue. A number of rather elaborate and costly devices for drawing off the test sample have been devised, none of which the average engineer is likely to use. The writer is of the opinion that a single pipe or tube, open at the end, and perforated throughout a portion of its length, will give a very fair average sample of the gas. This pipe should be placed in the boiler pass, uptake, breeching, or wherever the gas sample is to be drawn, with its open end at the point where the gas velocity is greatest. Whenever the pipe is inserted care must be taken not to allow a large leakage of air into the boiler setting to dilute the sample. If the pipe is inserted through an inspection or a clean-out door, don't leave the door ajar. Use every possible precaution to keep the air out. If the sampling pipe is inserted through a hole in the breeching, make the hole just large enough for the pipe.

When drawing a sample in this way for use with the Orsat apparatus, care must be taken to draw all the air from the pipe and its rubber hose connection before beginning to make an analysis. This can best be done by discarding the first four or five samples of gas which are drawn into the apparatus by simply discharging them through the three-way cock K, Fig. 1, into the atmosphere. In this way all the air in the sampling pipe and its connection is drawn out and a good sample of gas obtained.

Fig. 2 shows an extremely compact and handy flue-gas apparatus designed by Mr. Joseph W. Hays. It

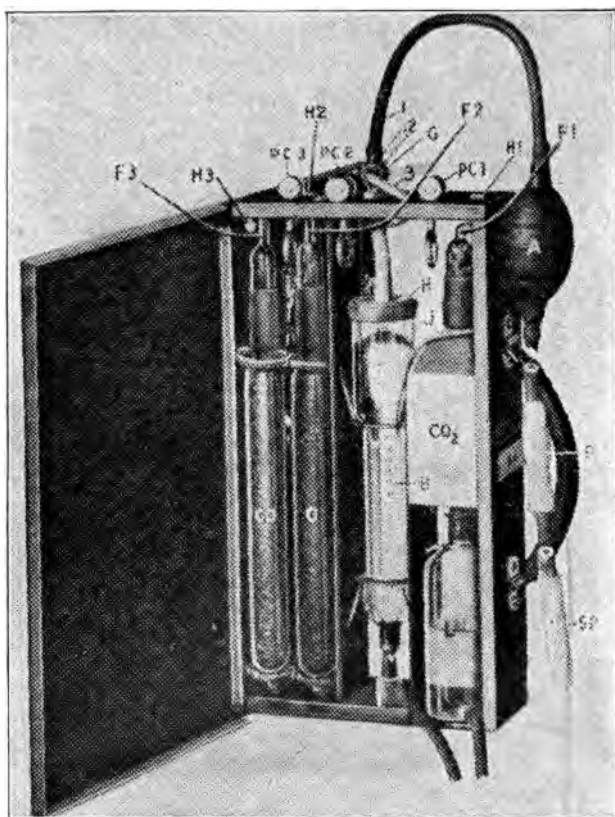


FIG. 2.

consists of measuring burette, reagent bottles for determination of CO_2 , oxygen and CO, much the same as the Orsat apparatus. The leveling bottle L is connected to the bottom of the measuring burette B and

is used in exactly the same way as in the Orsat. One good feature of this apparatus is the rubber tube and bulb A, connected between the top of the measuring burette and the gas-sampling pipe. With the leveling bottle L filled with water, gas may be drawn from the flue through the measuring burette B by simply pressing bulb A until it bubbles through the water in L. In this way a large amount of gas may be drawn through the apparatus and discharged until a good sample of gas is obtained. This Hays apparatus is smaller and more compact than the Orsat, contains less glass, and is therefore not so easily broken, and is put up in portable form.

Questions and Answers.

Q. What is the best known apparatus for boiler-flue-gas apparatus?

A. The Orsat.

Q. What gases are usually determined with this apparatus?

A. CO_2 , CO and free oxygen.

Q. What chemicals are used to dissolve or absorb these gases?

A. Caustic potash for CO_2 , potassium pyrogallate for oxygen, and cuprous chlorid for CO.

Q. How large a sample of flue gas is tested in the Orsat apparatus?

A. 100 c. c.

Q. How is this gas sample measured?

A. In a graduated measuring burette.

Q. What important point must be kept in mind when measuring the gas?

A. To measure it under atmospheric pressure.

Q. How can this be done?

A. By having the three-way cock open to the atmosphere when the final leveling is made.

Q. Before beginning the test where must the chemicals stand in the reagent bottles?

A. The surface of the chemical must stand at the mark on the neck of the bottle.

Q. Must the chemicals be brought back to this same point when the test is finished?

A. Yes.

Q. How much CO_2 will caustic potash absorb?

A. About forty times its volume.

Q. How much oxygen will potassium pyrogallate absorb?

A. Twice its volume.

Q. How much CO will cuprous chlorid absorb?

A. An amount equal to its volume.

Q. How should the gas be drawn from the flue?

A. Through a single pipe, open at the end and perforated for a portion of its length.

Q. Will the first charge drawn into the Orsat apparatus be a fair sample of the gas?

A. No; it will probably contain air drawn from the sampling pipe.

Q. What should be done with this first sample of gas?

A. It should be blown out to the atmosphere through the three-way cock.

Q. How many charges should be wasted in this way?

A. Probably four or five; at least until the operator is sure that all the air has been drawn from the sampling pipe.

CHAPTER III.

It has been shown that the most efficient boiler furnace is the one that consumes **all** the combustible in the fuel with the **least** excess of air. It has also been explained that only by means of the flue-gas analysis can the engineer tell how much excess air is passing through his furnace. We shall assume, then, that these two facts are well understood, and also that the method of making the flue-gas test, as explained in Chapter II, is fully mastered. Let us now consider how an engineer can make a practical application of these principles to improve the efficiency of his boiler furnace.

He must first supply himself with a hand flue-gas instrument, of which there are a number of good makes on the market, the average cost of which is probably not far from \$30. A good, reliable draft gauge will be found extremely desirable, and will probably cost about \$10. A thermometer to give the temperature of the flue gases will be of much assistance; instruments specially designed for this purpose are on the market, but any reliable thermometer can be used, and will prove less expensive than the special flue-gas instrument. A thermometer sufficiently accurate for all practical purposes can probably be bought for about \$5. These three items of expense will comprise the whole outlay for apparatus, and if properly used the instruments will pay for themselves many times over in reduced coal bills.

Begin with the flue-gas apparatus, to determine just what kind of a furnace you have, whether good,

bad or indifferent, from a standpoint of efficiency. Make a flue-gas test on the boiler side of the damper; if the conditions are about as they are in the average plant, about 7 per cent or 8 per cent of CO_2 will be found in the flue gases. Now put the sampling pipe into the first pass of the boiler if it be a water-tube boiler, or at the rear tube sheet if it be a horizontal tubular boiler. This will give a sample of the furnace gases just as they leave the combustion space of the furnace and before they come into contact with the heating surfaces of the boiler. It will probably be found that the percentage of CO_2 at this point is somewhat greater than was found just below the damper. The only explanation for this state of affairs is that the furnace gases are being diluted as they pass through the boiler. This dilution of the gases is caused by air leaking into the setting through cracks in the brickwork. It is easy to underestimate the amount of this air leakage, many engineers believing that it has practically no effect upon furnace efficiency. Unless your brickwork is better than the average, you will probably find from 1 per cent to 2 per cent less CO_2 at the damper than at the first pass, and this difference is due entirely to air leakage.

If this is found to be the case, attention must be given to the brickwork, to make it just as nearly airtight as possible. When it is remembered that the average air pressure inside the setting is about $\frac{1}{2}$ inch of water below atmosphere, and that all the cracks and holes in the brickwork are trying to satisfy that partial vacuum, an idea may be gained of how large an amount of air gets in in this way.

These leaks must be located and stopped. Take a coal oil torch and go carefully over all the brickwork; whenever a leak is found the flame will be drawn into the crack, showing that air is passing in at that point. Examine **particularly** around clean-out

and inspection doors, along the line where the brickwork closes in around the shell in the case of a tubular boiler, and at all points where for any reason the brickwork may be defective. If there are two or more boilers set in a battery, and the boiler next to the one under examination is "dead," examine the dividing wall with care. Frequently these walls are poorly built and serious leakage may occur through them when one boiler is out of service.

The moment a leak is discovered, stop it up. A pail of whitewash, into which some glue has been dissolved, will make a good filler for the cracks. Paint the brickwork over generously with this solution wherever a crack is found, care being taken to work it well into the holes. When dry, test again with the torch to make sure that the leak has been stopped. This will require considerable patience and involve work, but there is no doubt but that in the average boiler plant it will mean a saving in coal large enough to make all the work and trouble **decidedly** worth while.

Many engineers are so convinced of the importance of a tight boiler setting that they provide a complete insulating covering for the brickwork. Such a covering may be made as follows: Cover the surface of the setting with a layer of asbestos cement or plaster from 1 inch to 2 inches thick; cover this plaster with canvas and then apply a generous coat of paint to the canvas. This produces a setting which is as near airtight as it is possible to make it, and while it is considerably more expensive than filling the cracks with whitewash and glue, it makes a much more finished job and will last a considerable length of time.

When the leaks in the setting have been stopped it will be found that the CO_2 at the damper is practically the same as at the first pass. But even yet the percentage of CO_2 may be less than it should be and

it will be necessary to look further for the causes of excess air. In this connection a careful study of draft conditions will be of great importance, for it will assist in arriving at the most efficient operating conditions.

Draft, as every engineer knows, is caused by the difference in weight between the hot gases inside the smoke stack and a column of air of equal height and diameter outside of the stack. There is, therefore, a difference in pressure between the inside of the furnace and the outside, and this difference in pressure forces air through the furnace and boiler and up the chimney. The function of the draft is therefore to supply air to burn the fuel, and in general the greater the draft the more fuel can be burned. If the draft in any particular case is too great, an excessive amount of air will be forced through the fuel bed; portions of the grate will be burned bare of coal, producing holes in the fire, through which large quantities of air will rush, thus further increasing the excess. If the draft is insufficient, the combustion will be incomplete with the formation of smoke and CO in the flue gases, and it will be impossible to carry the load.

In order to determine what is the proper draft for a particular boiler operating under given load conditions, a series of tests must be made with the flue-gas apparatus and the draft gauge. The tendency in many cases is to use too much draft rather than too little, with the result that too great an excess of air is drawn through the fuel bed. Measure the draft over the fire and at the same time make an analysis of the combustion gases from the first pass of the boiler. Then either increase or decrease the draft very slightly by opening or closing the damper respectively, and again observe draft and CO₂. If the CO₂ has increased you are moving in the right direction; if not, move in the opposite direction. In this

way, by making very small changes each time, discover what draft gives the highest possible percentage of CO_2 consistent with satisfactory operation. You must, of course, carry your load, no matter what happens to the CO_2 , and the draft must not be reduced to the point where the steam gauge begins to fall. Also, when reducing the draft, watch for CO in the flue gases; this indicates incomplete combustion, and marks the point beyond which draft reduction must not be carried.

By a careful study of flue gas and draft it will thus be discovered what is the proper draft for maximum efficiency with your particular load. Note the position of the damper and keep it there as long as the load remains the same. When the load changes, a different draft and a different position of the damper will be necessary. An engineer should know accurately how much draft is required for a light, medium and heavy load, and should see that the damper is kept in the proper position to give that draft. Of course, it is much easier to operate under all conditions of load with a wide-open damper, but it is wasteful of coal, and coal costs money.

In changing the draft to meet varying conditions of operation, it is usually better to do it with the damper as suggested above, rather than with the ash-pit doors. If the draft is varied by means of the ash-pit doors while the damper remains wide open all the time, the full draft of the stack is pulling on the furnace continually. If the ash-pit doors are nearly closed, the effect of such an arrangement is to greatly increase the amount of air drawn into the furnace at **all other points**. The amount of air drawn in over the fire, as well as that getting in at any imperfect places in the setting, will be increased. On the other hand, if the damper be partly closed when less draft is desired, the "pull" of the stack will be reduced, which will

cause a proportional drop in the draft at all parts of the setting. Thus the same **relative** amounts of air will be drawn in over the fire and under it as before, so that combustion conditions will remain about as they were.

The relation between air admitted through the fire to that admitted over it is one that must be determined by each engineer for his particular conditions. It will vary considerably with the method of firing and the kind of fuel used. A bituminous coal which has a high volatile content and which is fired by hand requires a considerable amount of air over the fire. When a charge of such coal is thrown into the furnace a large volume of volatile combustible gas is distilled. Considerable air must be admitted over the fire to consume this gas, otherwise CO and smoke will be produced. When the volatile gas has all been consumed and only fixed carbon remains, the air coming **through** the fire will be sufficient for combustion and that coming in over the fire may be shut off. Thus in a hand-fired furnace the amount of air over the fire must be changed from time to time to suit conditions. Here again the flue-gas apparatus will be a reliable indicator of furnace conditions. Too much air over the fire will be just as serious from a standpoint of efficiency as too much through it. Discover by means of the flue-gas test the proper manner of air control for your furnace and then stick to it.

It has been pointed out that too much draft has a tendency to burn holes in the fire through which a large amount of air passes, diluting the furnace gases and reducing efficiency. The remedy is to reduce the draft and carry a thicker fire. In the case of a boiler under very light load it may happen that if the fire is thickened much the safety valve will blow off, while if the draft is reduced enough to prevent holes in the fire imperfect combustion and smoke will result.

This is an extremely difficult condition under which to operate a boiler furnace efficiently, because there is too much grate surface for the work required of the furnace. If the boiler operates habitually under such a light load, steps should be taken to reduce the grate area. If, however, the underload occurs only for a comparatively small portion of the time, all that can be done to improve efficiency is to reduce the draft as much as practicable and then carry as uniform a fire as possible, care being taken to prevent holes.

A boiler served with a chain-grate stoker and operated under a light load is almost sure to show inefficient combustion. A bare space a foot or more in width will be seen at the back of the grate as well as holes here and there in the fire. Since the grate surface can not be reduced, there is no remedy except to increase the load. In fact, with water-tube boilers and chain-grate stokers it may be put down as a practically invariable rule that it is good economy to operate one unit at 50 per cent or more overload than two units at 75 per cent of rating.

In all questions about air supply to a boiler furnace, rely on the flue-gas apparatus to give the correct answer.

Questions and Answers.

Q. Where should a flue-gas sample be taken for analysis to show combustion conditions?

A. Usually on the boiler side of the damper.

Q. What would a test at the first boiler pass show?

A. The quality of the gas as it comes from the fire.

Q. Will there be any difference in the gas at these two points?

A. Yes; the CO_2 will usually be higher at the first pass than at the damper.

Q. What is the reason for this?

A. Infiltration of air through the setting.

Q. How may the leaks in the setting be located?

A. With a flaming torch; the flame will be drawn into the cracks by the draft.

Q. How may the leaks be stopped?

A. By filling them with whitewash in which glue has been dissolved.

Q. How may a boiler setting be covered to prevent all leakage?

A. With asbestos cement or plaster, covered with canvas and painted.

Q. What is the function of draft in a boiler furnace?

A. To burn fuel.

Q. What happens when the draft is too strong?

A. Holes are burned in the fire, and efficiency goes down.

Q. What happens when the draft is too weak?

A. Imperfect combustion results, with the formation of CO and smoke.

Q. How may the proper draft conditions for a given load be discovered?

A. By flue-gas analysis at different drafts.

Q. How should the draft be varied?

A. By the damper.

Q. Is it possible to operate a furnace at high efficiency under light load?

A. No.

Q. Why not?

A. There is too much grate area for the work required.

Q. Should a boiler ever be worked at light load if it can be avoided?

A. No; it is much better to run fewer boilers at an overload.

CHAPTER IV.

It was shown in a previous chapter that a careful control of draft is absolutely essential to high furnace efficiency. When the load on a boiler varies, the amount of fuel charged into the furnace is varied in proportion to the load demands. If good efficiency of combustion is to be maintained, the amount of air admitted to the furnace must be varied in practically the same proportion as the coal, so that combustion conditions may be maintained practically constant. This necessitates a careful supervision over the draft at all times, and under all conditions of load.

It has been pointed out that the proper draft for a given furnace, using a given quality of coal and operating under a given load, can only be determined by a careful study of the flue gas, together with the draft-gauge readings. It will be of considerable assistance in determining the proper draft to use under any set of conditions, if the engineer is familiar with average draft-pressure losses through a few of the boilers which are used most widely in commercial practice. With such figures at hand it will be easier to reach good conditions in any particular boiler. Also sources of trouble, such as faulty design, defective baffles, or dirty tubes, may be located simply by an analysis of the draft-gauge readings.

Fig. 3 shows a horizontal return tubular boiler served with a chain-grate stoker. The figures in the small circles show the average value of the draft at that particular point, expressed in inches of water. These figures are the average taken from a large

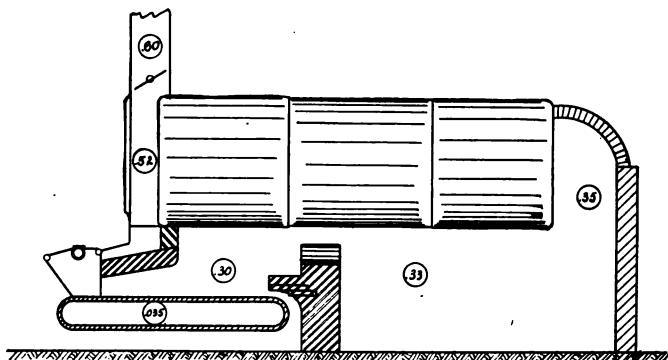
*RETURN TUBULAR BOILER*

FIG. 3.

number of observations, and may be relied upon as fairly representative of average draft conditions in a boiler of this type. It should be observed, however, that the **absolute** values given are not of so much importance as a guide in arriving at good draft conditions as the **relative** values. For example, if the load on the boiler were to decrease considerably, a thinner fuel bed would have to be carried. In order to prevent too great a quantity of air being drawn through the fire the damper must be partially closed. This might reduce the draft at the front tube sheet from 0.52 to, say, 0.40. But if the boiler and setting were properly designed and in good condition there would be a proportional decrease in the draft at all other points. Over the fire it would probably be reduced to about 0.23 instead of 0.30.

On the other hand, if the dampers were not partially closed when the load decreased, wasteful furnace conditions would result and the draft readings would show it. The draft at the front tube sheet

would still remain at about 0.52 because the position of the damper is unchanged. But since the fuel bed is now much thinner than before, the pressure drop through it would be much less than it was. The reading over the fire would be reduced to 0.20 or even less. Since the draft below the damper is unchanged, this would mean a vast excess of air drawn through the thin fire, with a consequent loss in furnace efficiency. It will be evident, therefore, that much may be learned about furnace and boiler conditions by a study of the draft at various points in the setting. If the draft readings bear the same general relation to each other as is shown in Fig. 3, the conditions are about right. Any marked departure from these proportions indicates poor practice.

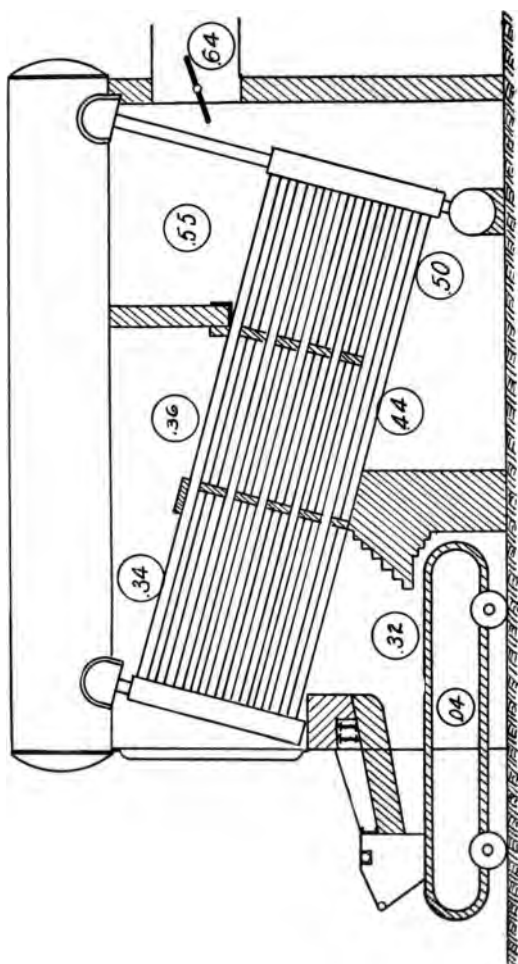
Suppose, for example, that the draft in the combustion chamber back of the bridge wall were found to be 0.40 instead of 0.33. This would mean too great a loss of draft pressure over the bridge wall. The only explanation for such a state of affairs is that the space over the bridge wall is too small, requiring a high gas velocity at this point with a consequent large drop in pressure. The remedy is to provide greater space at this point by lowering the bridge wall. In general, this space should be large enough to allow for a maximum gas velocity not to exceed 35 to 40 feet per second. If the maximum rate of combustion for the furnace has been predetermined (by an analysis of the probable load), and the kind of fuel to be used has been decided upon, it is possible to calculate the volume of gases which must pass over the bridge wall, furnace temperature being taken into account. It is then a comparatively simple matter to calculate the area required over the bridge wall. But if the boiler is overloaded more than was originally anticipated, or if a coal is used which has a larger volatile content than was expected, then the

calculated area will prove insufficient. The result will be too large a drop in draft pressure over the bridge wall, which can be detected immediately by means of the draft-gauge readings.

In like manner faulty boiler design can be detected by the draft readings. If the tube area is too small the draft loss through the boiler will be excessive, while if it is too large the draft loss will be less than that shown in the figure. Tubes clogged with soot and dirt will increase the loss through the boiler, so that it is possible to tell the condition of the tubes, to a certain extent at least, by the draft readings.

Fig. 4 shows a water-tube boiler of the B. & W. type, served with a chain-grate stoker, and with the average draft readings at various points given. It will be noted that the draft over the fire in this case is 0.32, just one-half of what it is at the damper. This is the same relation as was shown for the horizontal tubular boiler of Fig. 3. The boiler shown in this figure is vertically baffled, the gases passing three times across the tubes. The pressure drop is fairly uniform from fire to damper, showing no restricted portion in the gas passage, and no short circuit.

A boiler baffled in this way does not readily form short circuits through which the gases may pass, because there are no points in close proximity to each other which differ widely in draft pressure. Consider, however, what would take place if the front baffle should burn through at the bottom. Instead of passing up across the tubes the gases would pass through the hole in the baffle, thus finding a much shorter path to the stack. The result would be a serious loss in efficiency because the gases are not coming in contact with the tubes as they should, and hence do not give up their heat properly. A fault of this kind will usually be made apparent to one who understands the situation simply from the draft readings. In the



VERTICAL PASS BOILER ~ B & W TYPE

FIG. 4.

case of a short circuit as described the pressure drop between the fire and the rear of the bridge wall would be much less than 0.12, as shown in the figure. Such a short circuit can almost always be located by a study of draft-pressure drops from point to point through the setting in the normal path of the gases.

Restricted passages can be located in the same way, because in this case the normal draft-pressure drop will be increased.

Fig. 5 shows a Heine boiler, horizontally baffled. This boiler is quite similar to the B. & W. horizontally baffled type, so far as draft-pressure losses are concerned. It will be noted in this case that the total pressure drop through this boiler is greater than through the vertically baffled unit. The ratio between draft over the fire and at the damper is almost 1 to 3, while in the previous case it is 1 to 2. In a boiler baffled in this way the gases pass to the rear of the combustion chamber before striking the tubes. They then pass once over the tubes in the direction of their length instead of across the tubes as in the previous case. The bottom row of tubes has a covering of fire-brick tile, carried back to within 3 or 4 feet of the rear end. This forms a fire-brick roof for the furnace and greatly assists in the combustion.

A boiler baffled in this way has a tendency to develop short circuits, as will be apparent from a consideration of the figure. Over the fire the draft pressure is 0.28, while directly above, on the other side of the tile roof, it is 0.46. The same condition exists on opposite sides of the baffle on the top row of tubes. Below this baffle the pressure is about 0.36, while above it there is a pressure of 0.62. Thus there is a pressure difference on opposite sides of this baffle of 0.26 inches, which tends to produce a short circuit at that point. For this reason both the tile roof and the upper baffle must be watched closely for leaks,

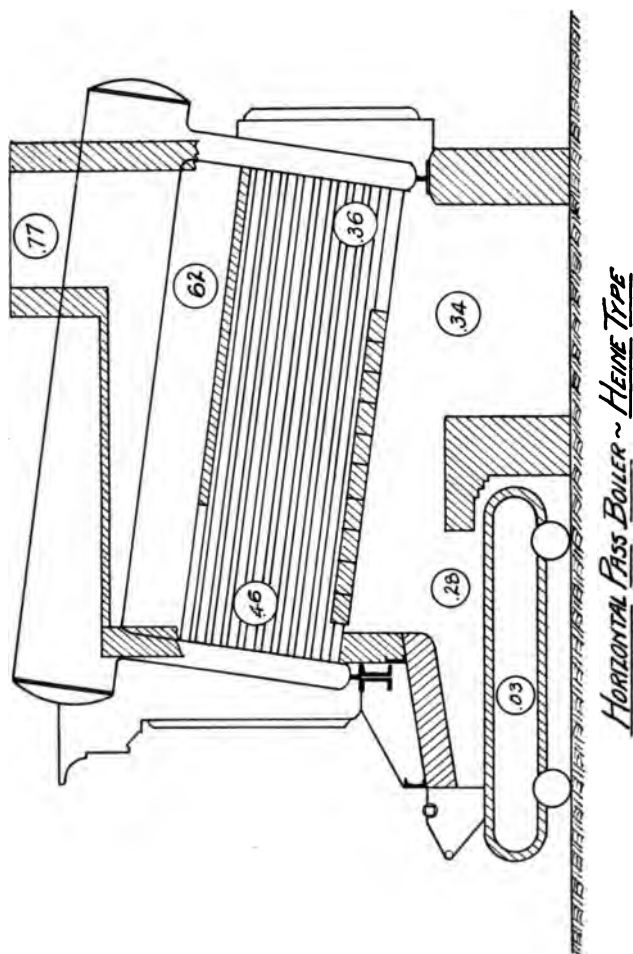
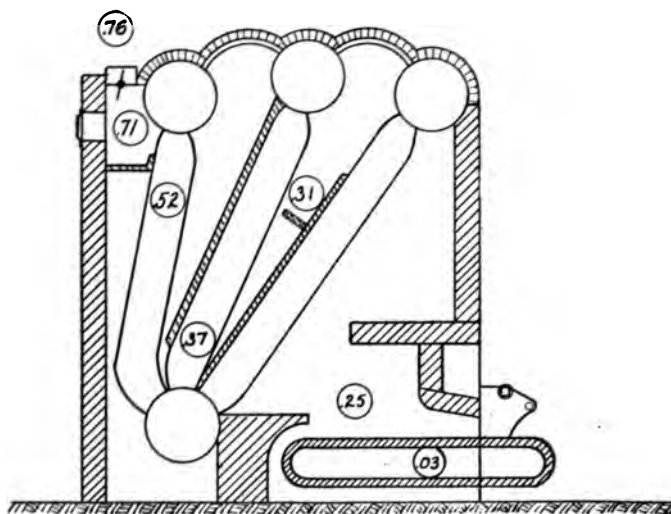


FIG. 5.

which become quite serious on account of the large pressure differences. Here again the draft gauge furnishes the information as to conditions inside the setting, if one is able to interpret these readings.

Fig. 6 shows a Stirling boiler with the draft-pressure readings indicated. It will be noted that the total



STIRLING BOILER

FIG. 6.

draft loss in this boiler is practically the same as in the case of the Heine type, horizontally baffled. The ratio between draft over the fire and at the uptake is practically 1 to 3, the same as for the Heine boiler. An inspection of the figure will show the points at which short circuits through the baffles are most

likely to occur. Such a point exists at the lower part of the first baffle just above the bottom drum. The tendency is for the hot gases from the fire to pass back over the bridge wall, through the first bank of tubes, and impinge on the baffle at this point. The tile becomes cracked and burned after a while and a leak is established. Draft readings taken over the fire and in the bottom of the second bank of tubes will furnish reliable information as to the condition of the baffle at this point. A very small pressure drop between these two points indicates a leak. The second baffle may be examined for leaks in the same way.

In all the figures shown thus far it will be noted that the draft over the fire is from 0.25 to 0.30. As has been already pointed out, this will vary with the thickness of the fuel bed. In general, the amount of coal which can be burned on the grate depends upon the available draft over the fire. Within certain limits, ten pounds of coal can be burned per square foot of grate area per hour for each 0.1 inch of draft available at the fire. This relation holds up to a combustion rate of about thirty pounds per square foot per hour, after which a disproportionate increase in draft is required for a given increase in combustion rate. The drafts given in the figures would therefore make possible a combustion rate of from twenty-five to thirty pounds per square foot per hour. When it is remembered that these furnaces are served with chain-grate stokers, which are efficient even at high rates of working, this rate of combustion will not seem excessive.

The importance of accurate information in regard to normal draft conditions in the different boilers is not easily overestimated. One is then in a position to note any departure from normal conditions, and to assign a reason for it. With the possible exception

of the instrument for flue-gas analysis, there is no single device which will give as much information about furnace and boiler conditions as the draft gauge, if intelligently used.

Questions and Answers.

Q. Why must the draft be regulated carefully as the load on a boiler changes?

A. Because the air admitted to the furnace must be properly proportioned to the fuel if good efficiency is to be maintained.

Q. How may the proper draft for any set of conditions be determined?

A. By means of the flue-gas analysis.

Q. Of what value is an accurate knowledge of average draft conditions throughout a boiler setting?

A. It makes it possible to locate furnace and boiler troubles.

Q. How would tubes or flues clogged with soot and dirt affect the draft readings?

A. This condition would be indicated by an abnormally large draft-pressure loss between the front and rear tube sheets.

Q. How would too small an area over the bridge wall be indicated in the draft readings?

A. By too large a drop between front and rear of bridge wall. Such a condition would also probably produce hot side walls and grates, due to the bottling up the hot gases in the furnace.

Q. How large an area should be provided over the bridge wall?

A. Large enough so that the maximum velocity of the gases will not exceed 35 to 40 feet per second.

Q. How would a leaky or broken baffle be indicated by the draft readings?

A. By abnormally low draft-pressure drop between opposite sides of the affected baffle.

Q. What is the chief factor determining the amount of coal which can be burned on a furnace grate?

A. The amount of draft available over the fire.

Q. What relation is there between available draft and rate of combustion?

A. About ten pounds of coal can be burned per square foot of grate area per hour for each 0.1 inch of draft.

Q. Does this relation hold indefinitely?

A. No; when the rate of combustion exceeds thirty pounds per square foot per hour the draft must be increased faster than the rate of combustion. To burn forty pounds of coal would require 0.42 inch of draft at least.

CHAPTER V.

It was shown in an earlier chapter that an efficient boiler furnace is one which burns all of the combustible of the fuel with the least possible excess of air. It was also pointed out, however, that there is a limit beyond which air reduction can not be carried without a drop in efficiency. This loss in efficiency is due to incomplete combustion, the most **noticeable** effect of which is the production of smoke. But smoke is only the **visible** effect of incomplete combustion, and is usually less serious from the standpoint of efficiency than the **invisible** effects, of which the smoke is the sign.

The Formation of Smoke.

When coal is fed into a boiler furnace, either by hand or mechanically, the first effect of the heat is to drive off the volatile gases which all coal contains in larger or smaller amounts. Anthracite coal may contain as low as 3 per cent of these volatile gases, while lignite may contain as much as 50 per cent. They are composed of hydrogen and carbon united in different proportions, and are usually referred to under the comprehensive term, "hydrocarbons."

The exact chemical action which takes place in the furnace when these hydrocarbons are brought into contact with air is probably not definitely understood. It appears, however, that at the temperature of the furnace some of these gases may be broken up into the elements of which they are composed; that is, into carbon and hydrogen. The latter element promptly

unites with the oxygen of the entering air, forming water vapor. If there is an abundant supply of air present, the free carbon also unites with the oxygen to form CO_2 . But if the air supply is insufficient, part of the carbon will form CO instead of CO_2 , and part of it may even escape from the furnace in the free state, that is, entirely uncombined with oxygen. This free carbon, deposited from the volatile hydrocarbon in the manner indicated, is what constitutes smoke.

The amount of free carbon which escapes in this way from the furnace and appears in the chimney gases is probably considerably less than is generally supposed, particularly by the public. A comparatively small amount of free carbon issuing from the top of the chimney is sufficient to give the gases a dense black appearance. In fact, it is unlikely if the amount of carbon lost in this way ever greatly exceeds 1 per cent of the total fuel. Thus from the standpoint of efficiency smoke in itself is not such a serious matter as is many times supposed.

But if the manner in which smoke is formed be kept clearly in mind it will be plain that there are other effects of incomplete combustion besides the visible smoke. These are CO , free hydrogen, and unburned hydrocarbons, all of which are invisible gases, and which may reduce furnace efficiency very seriously. For example, for each pound of carbon burned to CO instead of CO_2 , the loss is about 10,000 heat units. Thus, while smoke itself may not be serious from the standpoint of efficiency, it is of value as an index of bad furnace condition and poor efficiency.

Of course, it can not be denied that smoke is open to serious objection on humanitarian grounds, on account of its evil effect upon public health. For this reason the smoke problem has received a great amount of study, particularly in large cities. But to the power

plant owner smoke is important because it indicates serious conditions in the furnace which need attention if high furnace efficiency is to be maintained.

The problem for the operator of the boiler furnace is to secure complete combustion at all times with as little excess air as possible. This is by no means an easy task, and one that calls for a thorough understanding of combustion problems, and constant attention to furnace conditions. With a properly constructed furnace, a capable attendant and intelligent use of instruments such as draft gauges, CO₂ apparatus and thermometer, it is possible to obtain complete combustion with a fair grade of soft coal on as low as 30 per cent excess air. The United States Geological Survey gives the following table for an approximate heat distribution for Illinois coal. The same figures will hold true for all similar soft coals:

	Percentage of Heat.		
	1	2	3
1. Absorbed by boiler.....	50.0	65.0	75.0
2. Carried away in dry chimney gases.....	24.0	16.0	10.0
3. Radiation and unaccounted for losses.....	15.0	12.0	10.0
4. Moisture formed by burning of hydrogen.....	4.0	3.5	3.0
5. Evaporating moisture in coal.....	2.0	2.0	1.5
6. Incomplete combustion of carbon.....	5.0	1.5	0.5
Total heat.....	100.0	100.0	100.0

TABLE NO. I.

Column 1 above gives the heat distribution under poor conditions, Column 2 average conditions and Column 3 the best conditions practically attainable. These

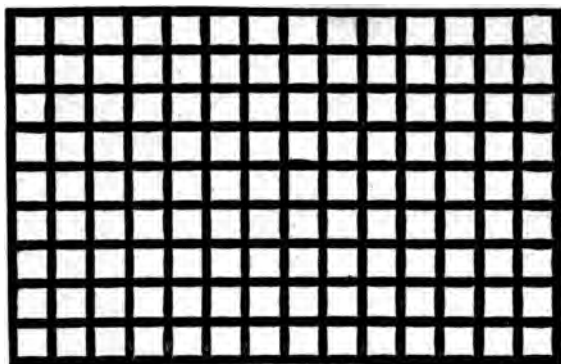
best conditions are rarely attained in present practice, but they are not impossible, and present a practical ideal toward which to strive.

The Observation of Smoke.

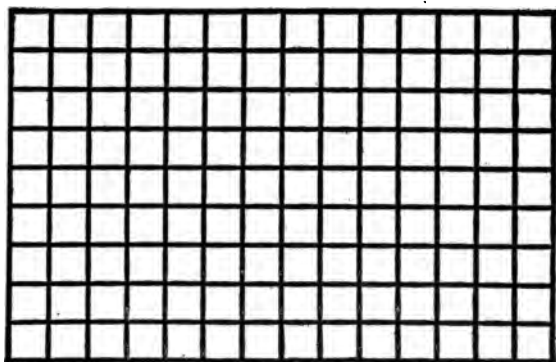
The casual observation of a smoking chimney may lead to very erroneous conclusions as to the amount of smoke coming from it. A stack may be practically free from smoke for 90 per cent of the time, and if smoke observations are made during the remaining 10 per cent of the day, a false idea is obtained as to the nature of the combustion in the plant. A standard of smoke densities is required, by means of which various smoking chimneys may be compared. Also careful time observations should be taken to determine the duration of the smoking, and the observations should be made at regular intervals throughout the day. Only by such a method can reliable results be attained.

The standard of densities which has the widest application in observing smoke is in the Ringelmann chart, devised by Professor Ringelmann, of Paris. This chart is shown in Fig. 7. Card 1 is made with black lines 1 mm. thick, 10 mm. apart, leaving spaces 9 mm. square. Card 2 has lines 2.3 mm. thick, with spaces 7.7 mm. square. Card 3 has lines 3.7 mm. thick, with spaces 6.3 mm. square. Card 4 has lines 5.5 mm. thick, with spaces 4.5 mm. square. In addition to the four cards shown in the figure, an all-white one is sometimes used and numbered 0, while an all-black card is numbered 5.

When making smoke observations, a chart is prepared which has the four cards shown in Fig. 7 arranged in a horizontal row. The all-white card and the all-black one may also be used. When this chart is observed at a distance of about 50 feet, the lines on

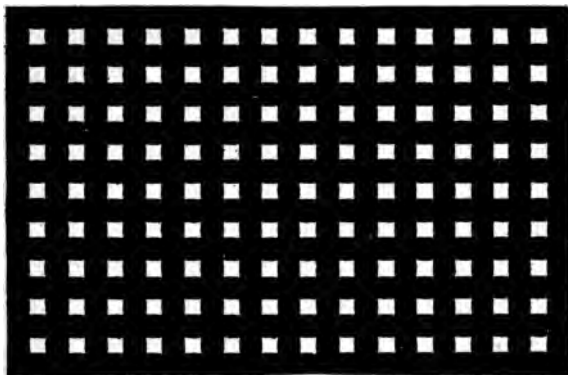


No. 2.

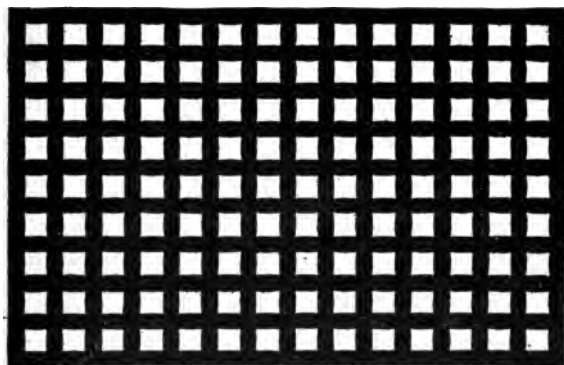


No. 1.

FIG. 7.



No. 4.



No. 3.

FIG. 7.

the cards can no longer be distinguished, the whole surface assuming a gray appearance. The heavier the lines on the card the darker the shade of gray which the surface appears to be.

In determining the density of the smoke, the observer glances from cards to smokestack and back again until he can pick out the card which most nearly corresponds in color to the smoke. If he should select Card No. 2 as most closely corresponding to the density of the smoke, then the latter is called No. 2 smoke. In the same way, one may speak of No. 1 smoke, No. 4, etc. In a boiler test these observations should be made at regular intervals throughout the day and the results platted on a smoke record chart, the smoke number being platted as an ordinate against the time as abscissa. In this way the smoke record for the whole day may be seen at a single glance.

Fig. 8 shows smoke of densities approximating the five cards of the Ringelmann chart. It will be noted that No. 1 smoke is a very light gray, such as is seen coming from many chimneys practically all the time. Such smoke is usually allowed by most city smoke ordinances. A chimney which never shows anything worse than No. 2 smoke would be considered good, while as dense as No. 3 may be permitted for brief intervals.

The Prevention of Smoke.

Smokeless combustion can only be secured by properly designed furnaces and eternal vigilance in operation. The first requirement is suggested by the way in which smoke is produced. Since it is caused by insufficient air supply, the first measure for its prevention is an adequate supply of air to the furnace at all times. The measures for smoke prevention may be enumerated as follows:

1. An adequate supply of air.

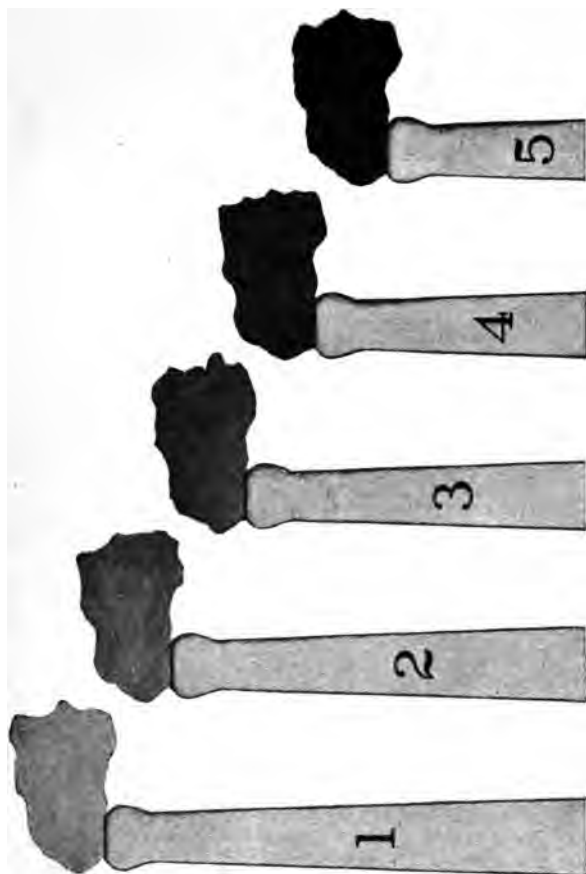


FIG. 8.

2. A temperature throughout the combustion zone high enough to provide for the complete combustion of the volatile gases or hydrocarbons.

3. A slow and uniform distillation of the hydrocarbons.

4. An intimate mixture of gases and air.

If these four requirements be met satisfactorily, then practically any soft coal can be burned without smoke.

The first requirement presents no great difficulty, since in the majority of steam plants far too great an excess of air is being used. The second requirement is very largely a matter of design, as it requires a brick or tile enclosed combustion chamber of such size and length that the hydrocarbon gases may be completely burned before reaching the heating surfaces of the boiler. Whenever a boiler is set over a furnace in such a way that the gases can come into contact with either shell or tubes before combustion is complete, smoke and poor economy are almost sure to result. When the flames strike the relatively cold heating surfaces they are chilled below the ignition temperature of the gases, combustion is arrested, and smoke produced. For this reason a tubular boiler set directly over the furnace almost always smokes when the flames come in contact with the shell. A brick or tile roof must be provided for the furnace or an arch must be built over the grates so that the flames can not strike the boiler until combustion is complete.

The third requirement, a slow and uniform distillation of the gases from the coal, is practically impossible when the furnace is fired by hand. In order that the distillation of the gases shall be slow and uniform, the fuel must be fed to the furnace at a uniform rate, and this is exactly what hand-firing does not do. When a charge of coal is thrown into the fire by hand there is a sudden evolution of gas while the coal is coking.

The quantity of gas given off at the time will very likely be beyond the capacity of the furnace to consume, and imperfect combustion will result. When the charge of coal has been completely coked, very much less air will be required to burn the fixed carbon. Unless the supply of air is reduced somewhat, too great an excess will be present, with a consequent loss in efficiency. Thus, on account of the widely varying demands for air on the part of a hand-fired furnace, it becomes extremely difficult to operate such equipment without smoke. The mechanical stoker which feeds the coal into the furnace uniformly and steadily makes smokeless combustion entirely practicable.

To promote the mixing of the gases and air, special features of design have been used, such as baffle piers, wingwalls, etc. In the next chapter these features will be discussed, as well as the general design of furnaces to promote smokeless combustion.

Questions and Answers.

Q. How is smoke formed?

A. By the incomplete or arrested combustion of the volatile hydrocarbons in the coal.

Q. Is smoke the only result of such imperfect combustion?

A. No, there is CO and unconsumed hydrocarbons in the chimney gases when smoke is found.

Q. How much heat is lost, due to the formation of smoke?

A. Much less than is generally supposed, probably not much more than 1 per cent of the total heat of the coal.

Q. Why, then, is smoke objectionable?

A. On humanitarian grounds, and because it is the visible sign of poor conditions in the furnace.

Q. How is the density of smoke estimated?

A. By comparing it with the cards of the Ringelmann chart.

Q. What is the first requirement for smokeless combustion?

A. An adequate air supply.

Q. Name some other requirements.

A. A high temperature in the combustion zone, a slow and uniform distillation of the gas from the coal, and a proper mixing of gas and air.

CHAPTER VI.

In Chapter V the requirements for smokeless combustion were enumerated and discussed somewhat in detail. We shall now consider some of the best types of modern furnaces, designed to burn high volatile soft coal without smoke, and note wherein they meet the conditions of smokeless combustion and wherein they fail to come up to the requirements.

Fig. 9 shows a Babcock & Wilcox boiler of 220 horse-power rated capacity, described by Professor Breckenridge. It is served with a Roney stoker, and equipped with the usual vertical baffling. Perhaps the chief feature of this furnace is the coking arch, placed over the front end of the stoker, so that the fresh coal is fed in directly under it.

This arch is of fire brick and is sprung between the side walls, the distance between grate and arch being shown in the figure. This arch is maintained at a high temperature, its purpose being to assist in the combustion of the volatile gases as they are distilled from the incoming coal. Experience has shown that this arch should be kept well down near the grates, to insure complete combustion of the gases. Professor Breckenridge states that, with careful handling, this furnace could be operated up to capacity without smoke above No. 2 on the Ringelmann chart. At 110 per cent of capacity and above it could not be operated without objectionable smoke, except by an expert fireman. The reason why this furnace smoked when operated much above normal boiler capacity is probably not difficult to see.

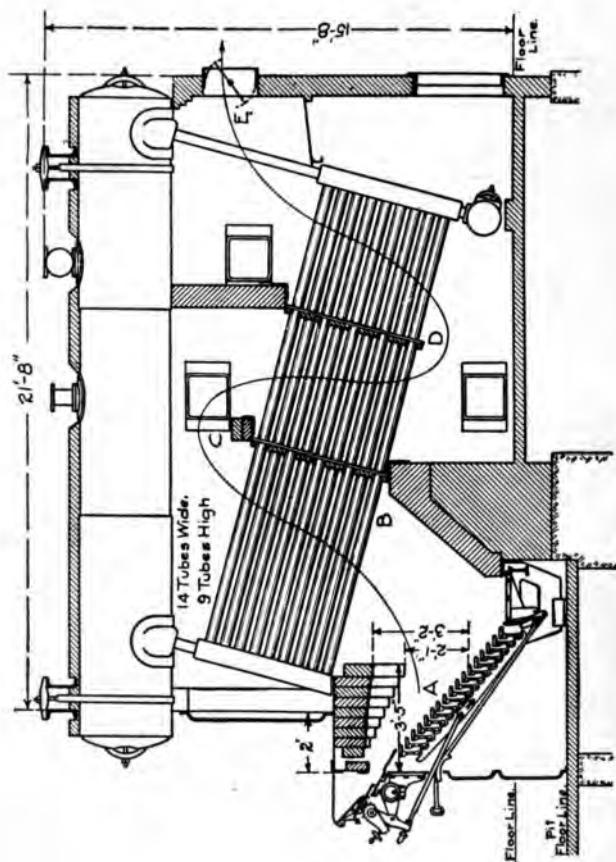


FIG. 9.

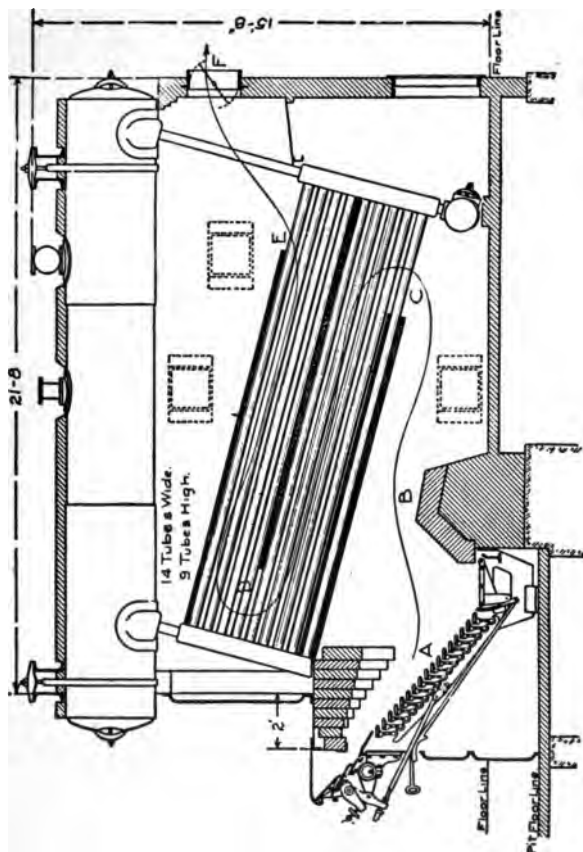


FIG. 10.

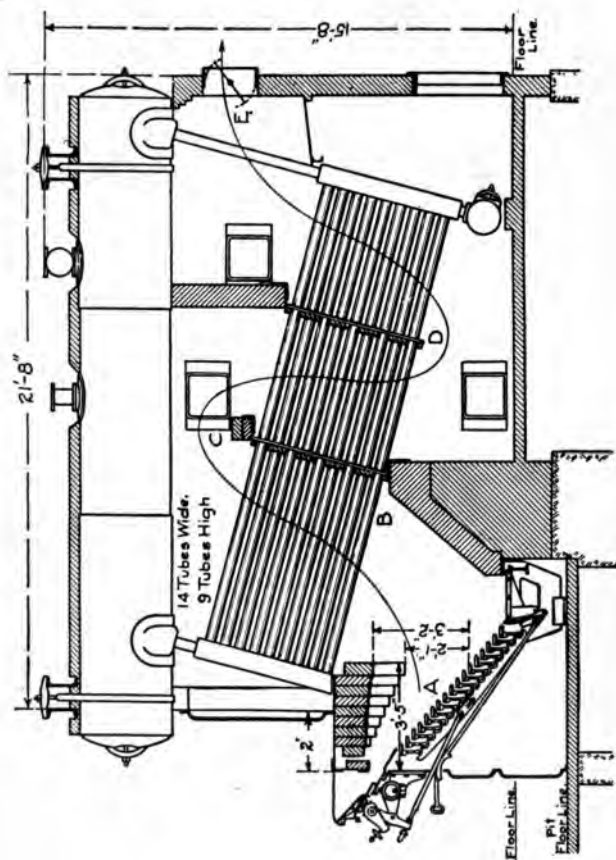


FIG. 9.

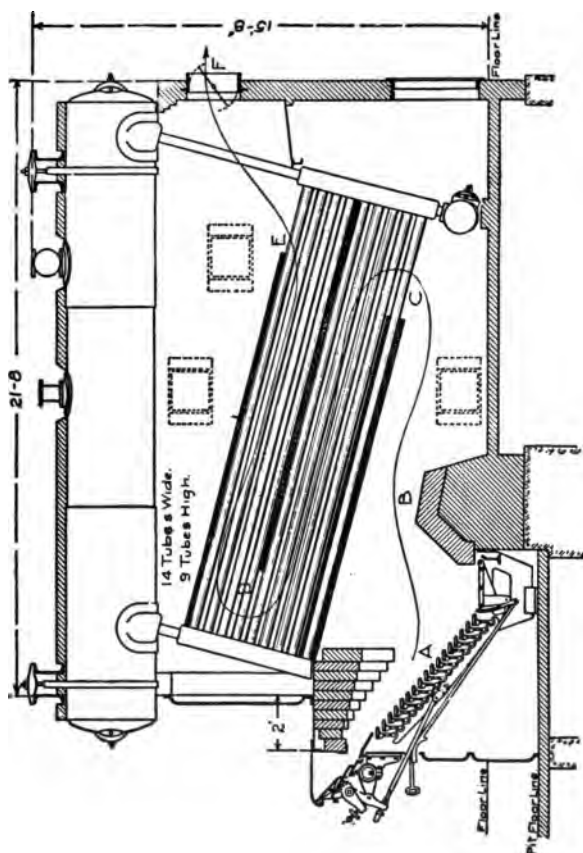


FIG. 10.

It will be noted that the distance between grates and boiler tubes is comparatively short. When the boiler was run at rated capacity the amount of coal burned, and hence the volume of gases to be consumed, was such that complete combustion was secured before the gaseous products of combustion reached the boiler tubes. Hence combustion was comparatively smokeless. On the other hand, when the boiler was forced beyond its rated capacity the volume of gases distilled from the coal was so great that complete combustion was impossible in the short distance from grates to boiler tubes. Hence the gases were chilled below their ignition point on striking the comparatively cold tubes, combustion was arrested and smoke produced. The chief trouble with this furnace is that it does not have a combustion space of sufficient length to provide for efficient combustion at high rates of working.

In general, it may be said that the area and length of the combustion space depend upon the rate of combustion and the character of the fuel. Or what amounts to the same thing, the combustion space must be designed with reference to the volume of gases which must be consumed per second. By combustion space is meant that portion of the furnace which is surrounded by fire brick, tile, or other refractory material, which may be maintained at a high temperature. The furnace under consideration has boiler tubes at the top of the furnace, which has the effect of greatly reducing the effective combustion space.

Fig. 10 shows a setting similar to Fig. 9, except that the boiler is horizontally baffled instead of vertically. A tile roof is provided for the furnace by means of specially designed tube tiles placed on the lower row of tubes. Professor Breckenridge states that this furnace could be operated at capacities up to 100 per cent of rating without smoke, and at greater capacities

without objectionable smoke. In this furnace the path of the gases is along the line ABC, and not until the point C is reached do the products of combustion come in contact with the heating surfaces of the boiler. Except at very high rates of working, the combustion space is sufficiently long to provide for complete combustion of the hydrocarbon gases before the point C is reached. Thus a furnace designed in this way is much better from the standpoint of smokeless combustion than the one shown in Fig. 9.

The draft required for this furnace will probably be somewhat greater than for the one with the vertical baffles shown in Fig. 9. But if sufficient draft is available there is probably no doubt that this furnace will prove superior to the vertical baffle so far as smokeless operation is concerned, particularly at the higher rates of working.

Fig. 11 shows a 210 horse-power Heine boiler, equipped with Green chain-grate stoker, and provided with mechanically induced draft. This boiler is installed in the Engineering Experiment Station at the University of Illinois, and has been used by the station in many practical fuel tests. It will be noted that the furnace is provided with a flat combustion arch over the front end of the grate, and that a roof is supplied by means of tiles on the bottom row of tubes. Experiments on this boiler show that it can be operated without smoke at practically any rate of working and under almost any conditions of operation. Ample draft being available, this boiler can be operated efficiently at very high overloads; in fact, Professor Breckenridge states that it was found to be almost impossible to make it smoke.

The chief features of design which are responsible for the smokeless operation of this furnace are: (1) The chain-grate stoker, which feeds the fuel into the furnace at a uniform rate, thus giving a steady

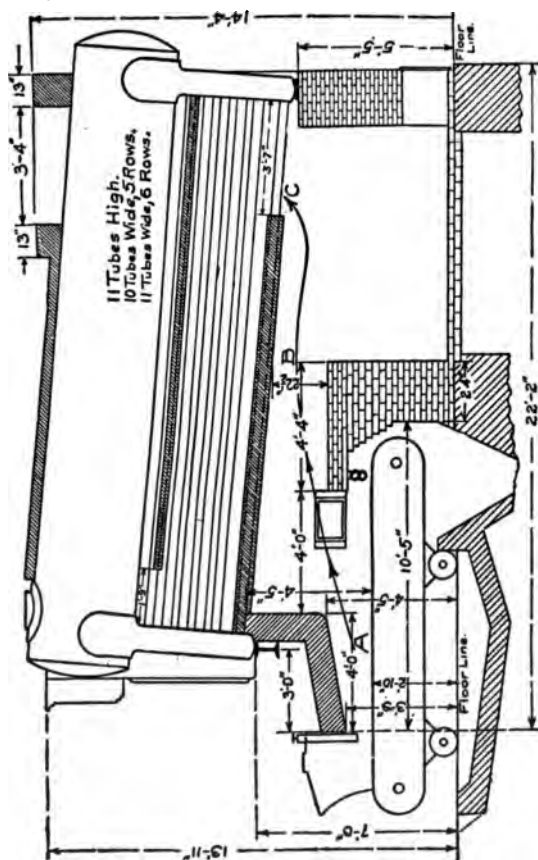


FIG. 11.

evolution of hydrocarbon gases, an important point in efficient combustion; (2) the combustion arch over the front of the grate, which ignites the gases as they come from the coal; (3) the tile roof, which prevents the gases from coming into contact with the boiler tubes until combustion is complete.

Fig. 12 shows a smokeless setting designed by Mr.

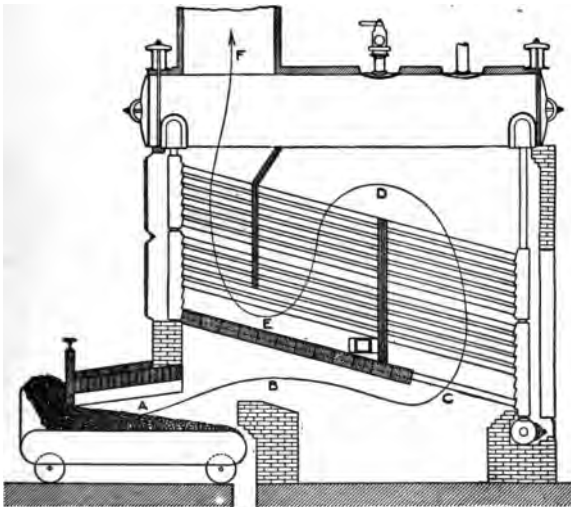


FIG. 12.

A. Bement, and described in the "Proceedings of the Western Society of Engineers," October, 1906. This is a Babcock & Wilcox boiler, with chain-grate stoker. A sprung combustion arch is provided over the grate, and a tile roof is placed on the bottom row of tubes. Unlike the setting shown in Fig. 10, this boiler has vertical baffles, the path of the gases being shown by

the irregular line ABCDEF. On account of such a devious gas path, considerable draft will be required to operate such a furnace satisfactorily, particularly at overloads. Also the area of the gas path through the various passes must be proportional with considerable care if good results are to be insured. Such a furnace, however, meets practically all the requirements for smokeless operation, and may be operated through a wide range of capacities without serious smoke.

Fig. 13 shows a Stirling boiler served with a chain-grate stoker, with a furnace designed for smokeless combustion. The chief features of this furnace are the flat ignition arch R, over the front of the grate, and the sprung arch P, above and behind the ignition arch. The function of the ignition arch is to assist in igniting and coking the fresh coal as it is fed into the furnace, the volatile gases being distilled gradually at this point. The sprung arch assists in the combustion of these gases; it is maintained at a high temperature and the gases roll over the edge of the arch and so are well mixed with air, which is an important point in smokeless combustion. This furnace, therefore, depends upon these two arches for good combustion, which is effected by the uniform distilling action of the first, and the mixing action of both.

It might seem at first sight that this furnace might smoke, inasmuch as the first bank of tubes is unprotected from the flame and hot gases. But experience has shown that such a furnace gives very good results from the standpoint of smokeless combustion, even at considerable variations in the rate of working. The path of the gases and products of combustion is shown by the irregular line ABCDEF; it will be noted that the gases do not impinge on the bottom of the first bank of tubes, but turn almost directly upward from under the end of the arch. By the time the gases



FIG. 13.

strike the tubes combustion is complete, except possibly at very high rates of working.

If the bottom of the first bank of tubes were covered with fire-clay tile, as in the case of certain other furnaces already described, combustion would hardly be improved to any extent because the gases do not strike the tubes at this point. On the contrary, the efficiency and capacity would probably be somewhat reduced, because the tubes at this point receive a considerable amount of heat from the fire in the form of radiant energy. If these tubes were covered with tile much of this radiant energy would be lost.

All of the smokeless furnaces discussed thus far are in connection with water-tube boilers and mechanical stokers. But there are a large number of fire-tube boilers in use in all parts of the country, the great majority of which are fired by hand. Such boilers are usually found in small plants, where hand firing is cheaper than mechanical stokers. The question of smokeless combustion in such a case as this is very difficult of solution and has not yet been satisfactorily solved.

In the first place, hand firing violates one of the chief requirements for smokeless combustion, namely, a slow and uniform distillation of the volatile gases in the coal. When a charge of coal is thrown into the fire by hand the gases are distilled faster than they can be consumed by the furnace, and smoke results. Hence smokeless combustion in a hand-fired furnace under all conditions of operation is almost impossible.

In Fig. 14 is shown a perspective view of a setting designed by the Department of Smoke Inspection of the City of Chicago, and recommended by them for use with the hand-fired horizontal tubular boiler. This is what is known as the double-arch bridge-wall furnace, and has given very good results when carefully operated.

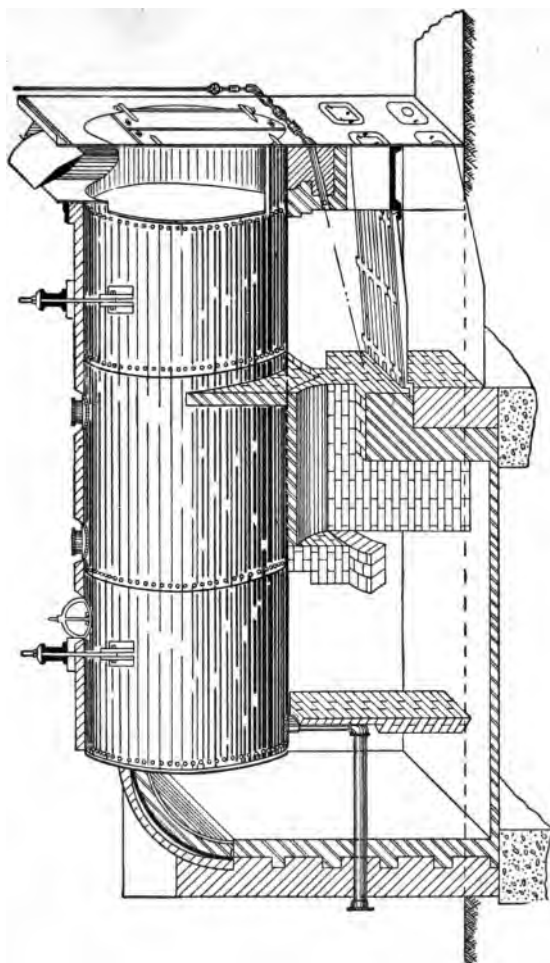


FIG. 14.

It will be noted that the gases coming from the furnace are divided at the bridge wall into two streams by means of a double arch rising from the center of the bridge wall. A bulkhead is built up around the shell to prevent the gases from escaping **above** the arch and so coming into contact with the boiler shell. Behind this double arch there is a short single arch sprung between the side walls. This is known as the deflection arch, its function being to deflect the gases downward after they leave the double arch, and so prevent them from impinging on the shell. The object of such a construction is to prevent the hot gases from coming into contact with the shell throughout practically its whole length.

A furnace of this kind will probably require more draft than the usual setting provided for such a boiler, on account of the devious path of the gases. Given sufficient draft, however, such a furnace greatly reduces the smoke nuisance when the firing is carefully done.

Questions and Answers.

Q. In practically all smokeless furnaces, how is a uniform distillation of the volatile combustible gases effected?

A. By an ignition or coking arch placed over the front of the grate.

Q. How is a uniform feed of fuel obtained in such a furnace?

A. By means of a mechanical stoker, usually some form of movable or traveling grate.

Q. What is the object in placing fire tiles on the bottom row of tubes in a horizontal water-tube boiler?

A. To provide a tile roof for the furnace and so prevent the gases from coming into contact with the tubes before combustion is complete..

Q. Can a hand-fired tubular boiler furnace be operated without smoke?

A. Yes, under favorable conditions and with careful handling.

Q. What kind of furnace has proved most satisfactory for such a boiler?

A. The double-arch bridge-wall furnace.

CHAPTER VII.

It will be evident from a reading of the foregoing chapters that furnace efficiency depends upon a number of conditions, such as character of flue gases, draft, design of furnace and grate, kind and condition of fuel, method of firing, etc. Many of these conditions are subject to considerable change, so that the problem of maintaining high furnace efficiency involves a constant attention to all the details of furnace operation. Furthermore, these conditions are such that a change which would adversely affect the efficiency might not be apparent to the fireman or man in charge. For example, it has been shown that in general a relatively high percentage of CO_2 in the flue gases is essential to high furnace efficiency. Also, we have seen that a leaky setting allows infiltration of air, which dilutes the gases, lowers the percentage of CO_2 at the uptake and decreases efficiency. Now, such a state of affairs can only be detected by a flue-gas analysis, as already explained, and this takes some time. The result is that in spite of flue-gas instruments, CO_2 records, draft gauges and thermometers, all of which are extremely valuable in their proper places and not for one moment to be underestimated, the fireman still does not have before him a constant and reliable index of what is taking place inside the furnace walls.

From a proper use of the instruments mentioned the engineer in charge has learned the best way to operate the furnaces under certain conditions of load. But he can not spend all of his time in the furnace-room watching the fires, so that for a part of the time, at

least, the fireman does not know if he is operating his furnace to the best advantage. If some instrument could be devised which might be placed on the boiler front, in plain view of the fireman, which would indicate at all times the efficiency of the whole steam-generating process, it would be a most valuable aid in maintaining proper furnace and boiler conditions.

It should be kept clearly in mind that these conditions can be determined with a fair degree of accuracy from the flue-gas analysis, draft and temperature readings, and the evaporation test. But the difficulty lies in **maintaining** conditions favorable to high efficiency after they have been determined. In the past it has been done by eternal vigilance, or (more often) not done at all. It will be apparent, therefore, what a vast amount of time and trouble would be saved, and what savings in fuel could be realized if some instrument were available which would give at a glance the efficiency of the whole steam-generating unit.

The Wilsey Fuel Economy Gauge is an instrument designed to meet just these requirements. It indicates to the fireman just what his combined furnace and boiler efficiency is at all times, and is practically as reliable in its action as the steam gauge. A fireman can usually be depended upon to keep the steam pressure at the right point, because he has the gauge always before him to guide him in his work. With the **fuel economy gauge** also before his eye he has a reliable guide to keep him in the path of high efficiency. Changing conditions in the furnace are **immediately** indicated on the economy gauge, and the fireman can go to work at once to correct them, without waiting for information from flue-gas apparatus or draft gauge.

One important distinction is to be made between the Wilsey Fuel Economy Gauge and all other instruments from which a knowledge of furnace conditions is obtained. These latter instruments give information

in regard to a single part or phase of the steam-generating process. For example, the CO_2 recorder gives information in regard to the **character of the combustion**, perhaps the most important step in the entire operation of steammaking. But still it is not the **whole** process, and the over-all efficiency **may** be relatively low, even with high CO_2 . Tubes lined with scale and covered with soot and dirt may produce just such a result. Similarly, the draft gauge and the pyrometer give information in regard to a single phase, respectively, of the steammaking process, not to the whole.

The Wilsey Fuel Economy Gauge is designed and constructed in such a way that it gives information in regard to the combined furnace and boiler efficiency. That is to say, it is affected not only by the efficiency of heat transfer from furnace gases to boiler heating surfaces, but also by the combustion conditions in the furnace. Thus the instrument is able to approximate very closely the efficiency of the whole process of steammaking, from coal to steam. In fact, if corrected for certain features, the neglect of which would introduce error, it will indicate efficiency with as great accuracy as an evaporative test.

In considering the principle upon which this instrument is based, think for a moment of what takes place in a furnace and boiler. The heat liberated from the fuel on the grate is carried away chiefly in two ways: (1) By radiation to the boiler and the furnace walls; (2) by heating the furnace gases, from which the heat passes to the boiler-heating surfaces by convection and conduction. By far the larger amount of heat passes to the furnace gases, and only a comparatively small amount is given off by radiation.

Now, if we neglect for the present the heat given off by radiation and other minor items, the heat liberated on the grate depends on the mass of furnace gas, its temperature and its specific heat. This gas passes

across the heating surfaces of the boiler and gives up its heat to the water. The heat remaining in the gases after they leave the boiler is lost up the stack. This lost heat depends upon the mass of gas, its specific heat and its temperature at the point where it leaves the boiler. The efficiency of the process is equal to the ratio of the heat used to the total heat liberated. In expressing this ratio it is not necessary to know the total mass of gas generated, because the heat in each individual unit mass is the same, being equal to the product of its absolute temperature and specific heat.

Let T = the absolute temperature of the furnace gases in the combustion chamber, just before they strike the boiler surfaces; let S = the specific heat of these gases. Similarly, let T^1 and S^1 = the absolute temperature and specific heat, respectively, of the gases leaving the boiler. Then the total heat per unit mass of gas coming from the furnace is TS ; also the total heat per unit mass of gas leaving the boiler is T^1S^1 . The heat absorbed is $TS - T^1S^1$, and the efficiency

of the process is $\frac{TS - T^1S^1}{TS}$. If R = a correction to be made for radiation, then the expression for efficiency becomes $E = \frac{TS - T^1S^1}{TS} \pm R$.

From a study of the formula it would appear to consider only heat absorption, and to disregard combustion entirely. But the better the combustion, the higher will be the value of T , and hence the higher will E become, if T^1 remains constant, that is, if the efficiency of heat absorption remains the same. This is an important point and merits some further consideration. Suppose, for example, that a boiler and furnace are operating under good conditions. Suppose draft and air supply are right, and the gases show 14 per cent CO_2 . The combined efficiency under these

conditions might be 70 per cent. If now there should be a considerable falling off in the load on the boiler, a much thinner fire will have to be carried on the grate. But if the draft is not promptly reduced so as to cut down the total amount of air passing through the furnace in proportion to the reduced rate of combustion, there will be a marked falling off in efficiency. But this loss in efficiency will be immediately indicated by the economy gauge, because the furnace gases will have their temperature reduced by the large **excess** of cold air which is being admitted to the furnace.

On the other hand, if an error in operation be made in the opposite direction and draft and air supply are too greatly reduced, incomplete combustion will result with the formation of CO and smoke. Again there will be a loss in efficiency, but this also will be indicated by the economy gauge, because the moment that the furnace gases are bottled up in the furnace and boiler passages, due to insufficient draft, there will be a rise in the temperature of the gases below the damper. Since the indication of the economy gauge depends upon $T - T^1$, a rise in T^1 reduces that difference and the instrument gives a lower reading.

Fig. 15 shows a diagram of the Wilsey Fuel Economy Gauge attached to a B. & W. water-tube boiler. It will be noted that one platinum loop is placed in the combustion chamber and the other in the uptake, and that these loops are connected to form two arms of a Wheatstone bridge. Two adjustable resistances within the instrument made up the other arms of the bridge. Across the bridge the indicating galvanometer is connected, with a series and a shunt resistance in its circuit.

A small battery current is passed through the bridge, and as the resistances of the platinum coils in the boiler vary by reason of the changing temperatures to which they are subjected, the bridge is thrown

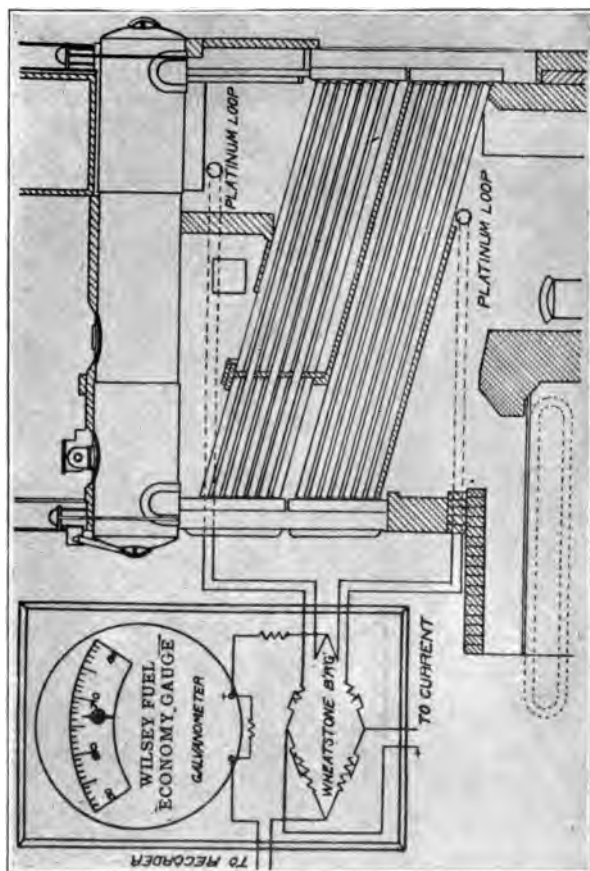


FIG. 15.

out of balance in proportion to the changing temperature at the two points. Now, in series with each platinum coil is connected an external resistance, the magnitude of which is proportional to the specific heat of the gases at the point where its respective platinum coil is located. That is to say, the coil in the combustion chamber has in series with it a resistance proportional to the specific heat of the gases at that point, and the coil in the uptake has connected to it a resistance proportional to the specific heat of the gases there.

Thus the current flowing in the two platinum coils becomes a function of the **total heat** of the gases at the points where the coils are respectively located, and the galvanometer will be deflected according to the ratio of the total heats at the two points. The correction for the effect of radiant heat from the fire is made by adjusting the resistance in series and in shunt with the galvanometer circuit.

It will be evident that an instrument of this kind must be carefully adjusted for each particular installation. To do this the boiler is run under the most efficient conditions possible, as shown by a careful test, and then the resistances in the four arms of the bridge are adjusted until the instrument indicates the efficiency shown by the test. After being properly adjusted, the economy gauge will instantly indicate any departure from the efficient conditions under which it was set. Thus the instrument exercises a watch on efficiency, and careful tests have demonstrated that its accuracy is only limited by the accuracy of the data upon which it is adjusted.

The coils, Wheatstone bridge and galvanometer are placed in a cast-iron box mounted on the boiler front in plain view of the fireman. The needle of the galvanometer shows through the glass front of the box,

the general appearance of the instrument being as shown in Fig. 16.



FIG. 16.

Table No. 2 gives the results of a number of tests run on a 500 horse-power Babcock & Wilcox boiler, under different conditions of operation. It will

be noted that the efficiency as shown by the Wilsey Fuel Economy Gauge agrees closely in each case with the results of the evaporative test.

Efficiency by Evaporation Per Cent.	Efficiency by W. F. E. G. Per Cent.	B. T. U. Per Pound.	Per Cent Ash.	CO ₂ .	Per Cent Rated Capacity Developed
68.9	69.1	9,580	17.2	12.4	158
68.7	69.1	9,850	16.7	12.2	130
66.7	67.4	10,584	11.8	11.8	141
66.2	67.4	9,505	19.8	11.3	146
65.9	66.5	9,598	19.5	11.7	147
67.1	66.8	9,815	16.6	12.2	153
65.8	64.6	9,440	19.5	10.6	127
65.8	64.7	10,053	13.8	12.2	156

TABLE No. 2.

It is a comparatively simple matter to connect a recording galvanometer to the economy gauge and thus get a continuous efficiency record throughout the twenty-four hours of the day. Fig. 17 shows a chart from such a recording instrument, taken on a 350 horse-power Stirling boiler. The period from mid-night to about 4 a.m., during which the fire was banked, is clearly shown on the chart.

The chief value of such an instrument as the one described here is probably to be found not so much in that it shows the efficiency at all times, as that it shows instantly any departure from proper operating conditions. The fireman can fire by the economy gauge to keep the efficiency high, just as he fires by the steam gauge to keep the pressure constant.

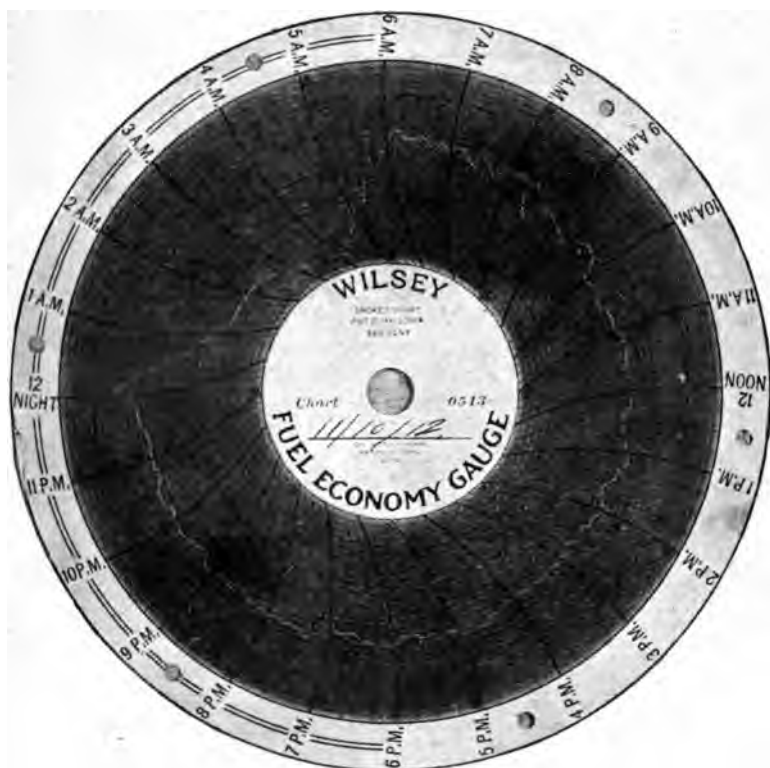


FIG. 17.

Questions and Answers.

Q. What is the function of the Wilsey Fuel Economy Gauge?

A. To indicate at all times the efficiency of the steam-generating process.

Q. Upon what does it depend for its operation?

A. Upon the difference in temperature of the furnace gases in combustion chamber and uptake.

Q. Does all the heat of the fuel pass to the gases?

A. No; some passes to boiler and furnace walls by radiation, and the fuel-economy gauge must be corrected for this heat.

Q. How is the Wilsey instrument constructed?

A. Two platinum coils are placed in the furnace and boiler, one in the combustion chamber and the other in the uptake. These coils form two arms of a Wheatstone bridge, so that any change in temperature of the furnace gases throws the bridge out of balance.

Q. What degree of accuracy will this instrument show?

A. Its indications will usually agree with the results of an evaporative test to within 2 per cent.

CHAPTER VIII.

It was shown in a previous chapter that proper draft conditions in furnace and boiler are of great importance in securing high efficiency. It was pointed out that a certain rather definite relation must exist between the draft pressure in the furnace and the different passes of the boiler if satisfactory operating conditions are to be realized. For example: the loss in draft pressure through the fire bears a relation to the loss through the boiler which is very nearly constant for any particular installation, even though there may be considerable variation in load. Of course, this relation varies in furnaces and boilers of different design, and must be determined experimentally and by experience for each particular type. But after this relation has been determined it furnishes a guide to efficient operating conditions which is of considerable value.

This fact has been utilized by Mr. W. A. Blonck to produce a boiler efficiency meter, which gives considerable information in regard to furnace conditions. This instrument, as will be seen from Fig. 18, consists of two sensitive draft gauges, mounted in a suitable case, one above the other. They are both differential gauges, the upper one being connected between the furnace and the boiler side of the damper and the lower one between the furnace and the outside atmosphere. Thus one gauge shows the draft pressure drop through the boiler and the other the drop through the fire. The tube of the upper gauge is filled with blue oil and the lower one with red oil.

Fig. 19 shows the complete meter, in shape to be mounted on the boiler front in view of the fireman. It will be noted that each draft gauge is provided with a pointer; these pointers are movable and are set by experiment on each installation. That is, a careful test of the boiler shows where each gauge should stand when conditions are known to be good. Then the movable pointers are set at these two points, and it becomes the duty of the fireman to keep the oil in the gauges as near them as possible.

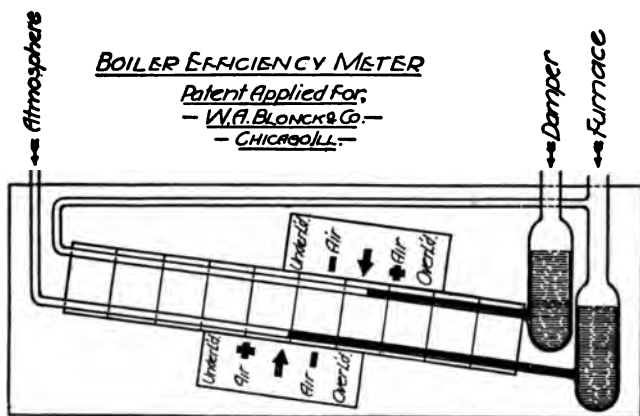


FIG. 18.

The function of a differential draft gauge is to indicate the **difference** in pressure between the two points to which it is connected. The situation is similar in principle to the manner in which a voltmeter indicates the difference in electrical pressure between two points. Now, as every engineer knows, the difference in pressure between the inside of the boiler and the outside is due to the difference in weight

between the furnace gases and an equal volume of air. This difference in weight causes a pressure which forces air through the furnace and boiler and up the chimney. As the air and gases pass through the setting from ash pit to chimney they encounter a

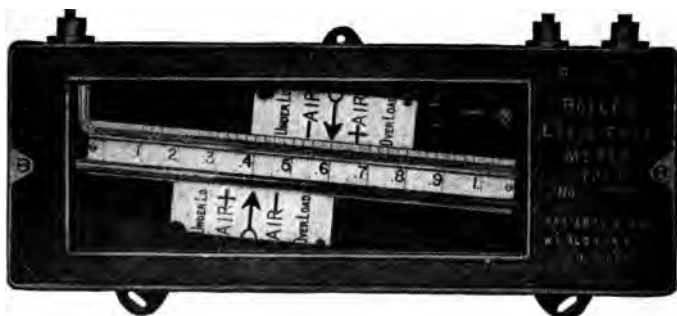


FIG. 19.

certain resistance to their flow. This resistance causes a drop in draft pressure, just as the electrical resistance of a conductor causes a drop in potential. The magnitude of this draft pressure loss depends upon the resistance encountered in the boiler passages and the rate of flow of the gases. That is, if one or both of the above quantities should increase, the pressure drop increases, while if one or both decrease, the drop decreases.

With the causes of draft pressure loss kept clearly in mind, it is possible to gain a fair idea of the principles underlying the operation of the Blonck efficiency meter. Consider first the lower gauge, which is connected between the furnace and the outside atmosphere. This gauge shows the **difference** in draft pressures between the two points to which it is connected; that is, it shows the **pressure drop** through

the fire. This drop, as already explained, will depend upon the resistance of the fuel bed and the rate of flow of air through the fuel. If the fuel bed is too thick or the fire is choked with ashes or slag, there will be a high resistance to the flow of air and consequently a large pressure drop through the fuel bed. This will be indicated by a high reading on the lower gauge. On the other hand, if the fire is too thin or there are holes in it, the resistance to the flow of air will be reduced to almost zero, and the pressure drop through the fuel bed will be greatly reduced.

Thus it follows that the reading of the lower gauge gives at all times a fairly accurate measure of the resistance of the fuel bed. This information, used in connection with the draft pressure drop through the boiler passages, is extremely valuable as a guide to correct furnace conditions.

Consider now the upper gauge of the meter, which is connected between the furnace and the boiler side of the damper. This gauge gives a measure of the draft pressure loss through the boiler, as distinguished from the furnace. Now the resistance to the flow of the furnace gases through the boiler is not subject to wide and sudden fluctuation as it is in the case of the fuel bed. Of course this resistance is subject to **some** change, such, for example, as might be due to accumulations of soot on the tubes or in the flues, defective baffles, etc., and the Blonck meter will give information in regard to just such conditions. But the point to be kept clearly in mind here is that changes in draft pressure loss in the boiler are chiefly due to changes in the **rate of flow of the gases**. It must be remembered that draft loss depends upon rate of flow and resistance, and since in normal operation the latter is nearly constant or at most varies but slowly, the draft loss becomes a fairly accurate measure of the rate of flow of the gases. Thus the blue upper

gauge gives a reading which is closely proportional to the amount of furnace gases passing through the boiler per unit of time.

If we wish to revert again to electrical terms, the upper gauge is an ammeter which shows the rate of flow through the boiler. The lower gauge partakes of the nature of a voltmeter, showing the difference in draft pressure tending to force air through the fuel bed.

When the Blonck efficiency meter is to be applied to a steam generating unit the chief consideration is to get it properly set. This should be done during the longest daily period of average load on the boiler, which will give as nearly **average** load conditions as it is possible to get. All operating conditions, such as thickness of fire, position of damper, method of firing, frequency of cleaning fires, etc., should be carefully regulated to give the most efficient operating conditions obtainable. In determining these conditions the hand flue gas instrument will be found to give much valuable information. When the desired conditions have been obtained the movable pointers shown in Fig. 19 are set to the points where the oil stands in the two gauges. It is now the duty of the furnace operator to keep the gauges as nearly as possible at these two fixed points. The manner in which the meter is connected to the boiler and the location of the draft tubes is shown in Fig. 20.

The action of the meter under different conditions of operation is as follows: Suppose that the fire becomes too thin, or holes burn in it, or it burns short at the back. This means that the draft loss through the fire will be small, and the red gauge will give a smaller reading than it should. But the large volume of air passing through the furnace and boiler will cause an increase in draft pressure drop between furnace and uptake. This will be indicated by a larger reading on the blue gauge. Such a condition as this is

shown in Fig. 21, Example No. 2 The relative position of the two gauges for normal operation is shown in Example No. 1.

When the fire is too thick, or choked with ashes and slag, there will be a greater drop than normal through the fire, while on account of the reduced air supply there will be less drop through the boiler.

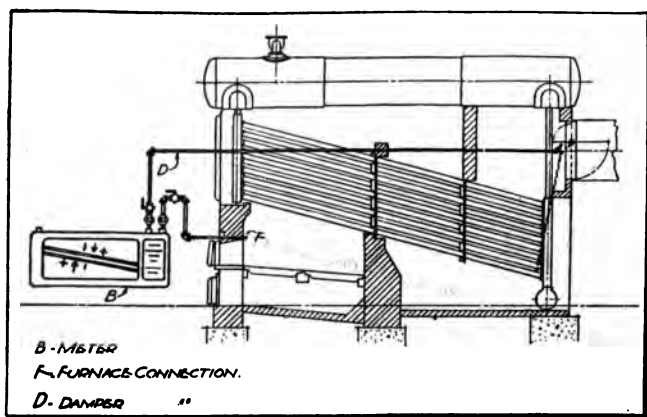


FIG. 20.

CONNECTIONS OF BOILER EFFICIENCY METER TO
WATER TUBE BOILER.

This condition is shown in Example No. 3. It will be noted that in the two cases considered thus far the two gauges moved in opposite directions from their normal points. This will be the case when the load remains practically constant, and the only change is in the condition of the fire.

In Example No. 4 is shown the indications of the meter when the boiler is running with an overload.

In this case comparatively thick fuel bed must be carried in order to supply the necessary rate of combustion. But the damper must now be wide open so as to furnish enough draft to force the required amount of air through the thick fuel bed. The result is an increase in the pressure drop through the fire,

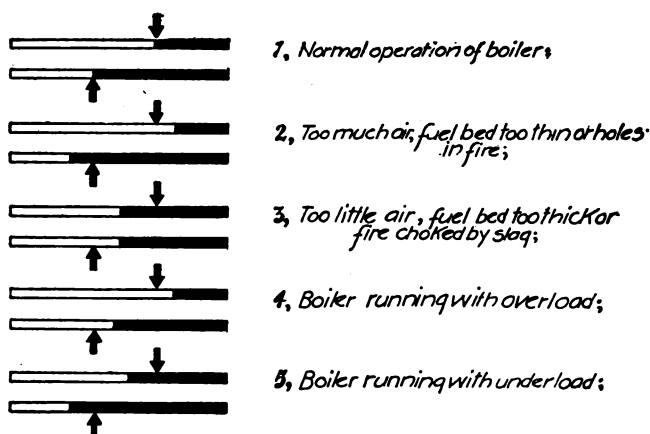


FIG. 21.

DIAGRAM OF BOILER EFFICIENCY METER AND PRINCIPAL INDICATIONS OF INSTRUMENT.

because both resistance and rate of air flow have increased. This gives an increased reading on the red gauge, the oil moving to the right as shown. But since more air is flowing through the fire than before, the pressure drop through the boiler increases. This gives a larger reading on the blue gauge, the oil moving to the right as shown. The conditions indicated by such a reading of the gauge (see No. 4) are satisfactory, because the ratio between furnace drop and boiler drop has not been changed to any extent.

Example No. 5 shows the indication of the meter under light load. In this case the fire is thin and the pressure drop through it is small, which gives a reduced reading on the red gauge. But the stack

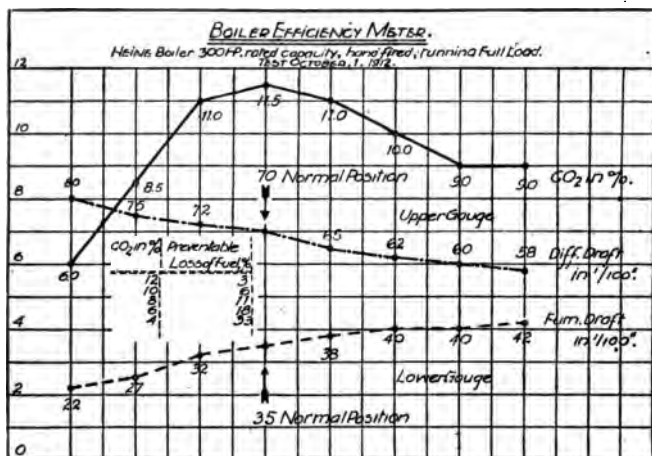


FIG. 22.

TYPICAL READINGS FOR A WATER TUBE BOILER.

draft has been reduced by partially closing the damper, so that less air is being forced through the fire in proportion to the reduced rate of combustion. This gives less pressure drop through the boiler and a reduced reading on the blue gauge, as shown. Here again the ratio of the two drops remains practically constant, so that conditions are about as they should be for this particular load.

The manner in which the indications of the meter show the conditions within the furnace and boiler is shown in Fig. 22. The upper curve in the figure shows

the percentage of CO_2 , which runs from a minimum of 6 per cent to a maximum of 11.5 per cent. The dotted curves show the reading of the upper and lower gauges, respectively, in hundredths of an inch. At the beginning of the test the CO_2 was 6 per cent, the upper gauge read 80 and the lower one 22. Now 6 per cent CO_2 indicates too much air. The fire was therefore gradually thickened, which increased the

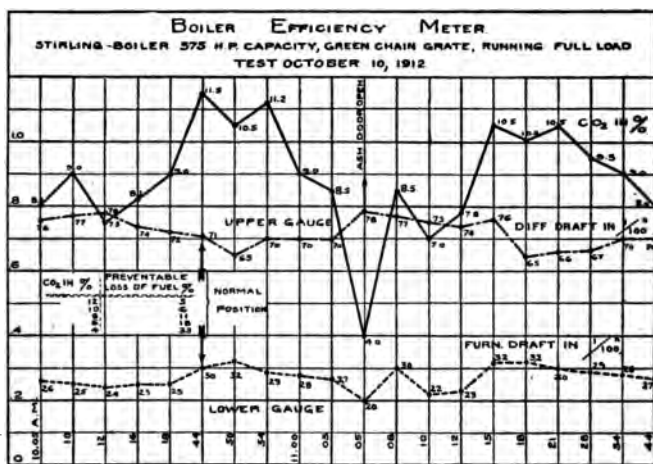


FIG. 23.

RESULTS OF TEST ON BOILER WITH CHAIN GRATE
 SHOWING EFFECT OF OPEN ASH DOOR.

pressure drop through the fire, but decreased the air supply. Therefore the lower gauge read more, the upper one less, and the CO_2 increased. This was continued until 11.5 per cent CO_2 was reached, when the lower gauge read 35 and the upper one 70. A further increase in thickness of fire carried air reduction too far, which resulted in the formation of smoke

and CO , with less CO_2 . Therefore the movable pointers on the efficiency meter were set at 70 for the upper gauge and 35 for the lower one.

Fig. 23 shows the result of a test of a 375 horsepower Stirling boiler, with Green chain grate stoker. The chief point of interest in these curves is the sudden drop in CO_2 at 11:05 a.m. It will be noted that the reading of the upper gauge of the meter increased at this time, while the lower one decreased. This expansion of the distance between the two gauges is an indication of inefficient conditions, as we have already seen, and thus agrees with the low CO_2 noted at that time. This condition was caused by the opening of an ash clean-out door in the basement, which resulted in excess air being admitted to the furnace. It will be seen from this figure that whenever the readings of the two gauges approach each other the CO_2 is high and combustion conditions are good, and that when the distance between the gauges increases the opposite results are noticed. This is true until the position of normal setting is reached.

Fig. 24 shows the results of a test on a 375 horsepower Wickes boiler, served with a Murphy stoker. These curves show the behavior of the meter during periods of excess air and lack of air, the shaded portions showing the nature of the air supply. The normal setting of the gauges is 77 for the upper one and 18 for the lower one. When the difference is greater than this there is excess air and low CO_2 , as at 12:17 p.m., for example. When the difference between the two gauges is less than normal there is fair CO_2 , but reduced steaming capacity, as shown at 11:52 a.m. This shows that CO_2 is not always a safe guide to high efficiency. When the air supply is unduly restricted the CO_2 may be fairly high, but there will also be CO , smoke, reduced capacity, and reduced efficiency. This condition is plainly shown by the meter,

the difference between the two gauges being less than normal.

Fig. 25 shows results taken from a test of a B. & W. boiler, with B. & W. chain grate stoker. The effect upon the efficiency meter of length of fire and

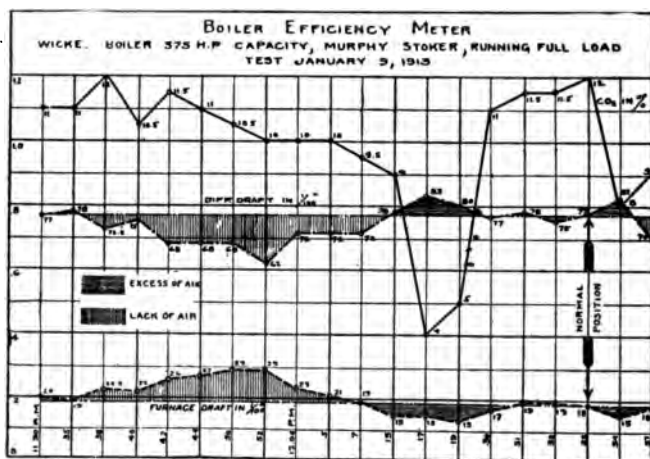


FIG. 24.

TEST SHOWING RELATION BETWEEN AIR SUPPLY AND CO_2 IN FLUE GAS.

thickness of fuel bed is clearly shown. The test was begun with a 9-inch fire, the upper gauge reading about 80 and the lower one 60. As the test continued the distance between the gauge readings increased, and the CO_2 dropped, indicating excess air and reduced efficiency.

At about 11:10 a. m. the thickness of the fire was increased to $10\frac{1}{4}$ inches, but the results did not become noticeable until about 11:35 a.m., because of the

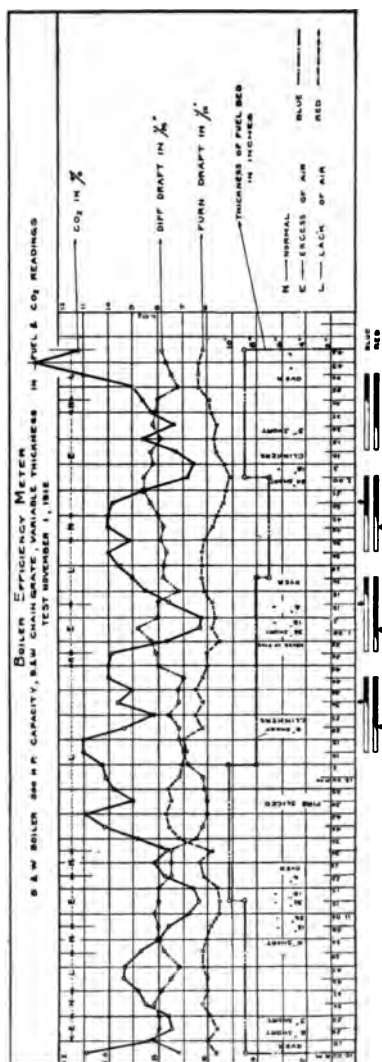


FIG. 25.

EFFECTS OF THICKNESS OF FUEL BED UPON EFFICIENCY METER.

slow travel of the grate. At this point it will be seen that the curves representing gauge readings crossed each other. That is, the draft pressure drop through the fire became greater than that through the boiler. This indicates too thick a fire, insufficient air passing through the boiler, and hence reduced steaming capacity, even though the CO_2 is fairly high.

At 12:05 p.m. the thickness of fire was reduced to 8 inches, with the result that the gauge reading curves recrossed each other, indicating that conditions were about correct again. A study of these curves will show that thickness of fire and length of fire, whether short or long, have an immediate effect upon the efficiency meter.

Fig. 26 shows the results of a test on the same B. & W. boiler, the object being to show the effect upon the efficiency meter of different rates of working, as shown by a General Electric Steam Flow Meter. The upper curve shows the instantaneous flow meter readings, while the average is shown by the dotted line. It will be seen that the curve representing average rate of evaporation is practically parallel to the curves showing the readings of the meter gauges. Thus the relative distances of both gauges from their normal points, indicated by the fixed arrows or pointers, are a measure of the load carried by the boiler. If both gauges go above this normal point, there is an overload; if below, there is an underload. (See Fig. 20.)

It will be evident from the curves that have been presented herewith that the Blonck Efficiency Meter can be relied upon to give much valuable information in regard to conditions in the furnace. Also, it gives this information almost instantly, so that faulty conditions can be corrected before serious loss can occur. If its indications are intelligently made use of, there can be no doubt but that the Blonck meter will greatly assist in maintaining high furnace efficiency.

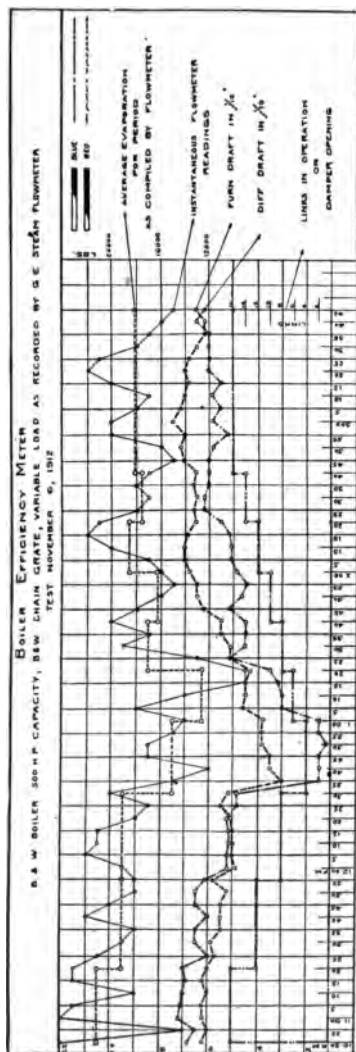


FIG. 26.

EFFECTS OF LOAD VARIATIONS UPON BOILER EFFICIENCY METER READINGS.

Questions and Aswers.

Q. What are the essential parts of the Blonck Boiler Efficiency Meter?

A. It consists of two differential draft gauges.

Q. How are these gauges connected in the furnace and boiler?

A. One is connected between furnace and outside atmosphere, and the other between furnace and boiler side of damper.

Q. What do these gauges show?

A. One shows draft pressure loss through the fire and the other the loss through the boiler.

Q. How can these readings indicate efficiency?

A. They show the relation between furnace loss and boiler loss, which have a nearly constant relation when efficient conditions are maintained.

CHAPTER IX.

The Chain Grate Stoker.

It was shown in a previous chapter that one of the most essential conditions for efficient and smokeless combustion is a slow and uniform distillation of the volatile gases from the coal. This requires a gradual and continuous feeding of the fuel into the furnace, so that the evolution of the gas may be maintained at a uniform rate.

This principle has been recognized by engineers for some time, and has been kept prominently in mind in the design of most mechanical stoking devices. It is known as the principle of progressive combustion, the fuel being carried gradually forward into the furnace as the combustion progresses. Even before the days of mechanical stokers when all boiler furnaces were fired by hand, this principle was applied to a limited extent. It consisted in charging the green fuel onto a dead plate just inside the furnace door, where the volatile gas was driven off. When the coal had become fairly well coked it was then pushed back on the grate where the combustion of the fixed carbon took place. This method of firing is still made use of in many hand-fired furnaces, but it is, of course, open to the serious objection that large quantities of cold air enter the furnace while the fire-door is open, and thus the efficiency is reduced. This same objection applies to a greater or less extent to any method of firing by hand.

The chain grate stoker is a device which provides for this method of progressive combustion, while at

the same time excluding all unnecessary air from the furnace. The first stoker of this kind was designed in England, but it is now used very largely in this country, American designers and engineers having added many improvements over the original design, by which it is better adapted to American coals. It consists of a moving endless chain mounted on a frame, the fuel being carried forward on the chain. This method of feeding the coal into the furnace is an almost ideal application of the principle of progressive combustion. The volatile gases are first driven off by the heat radiated from the incandescent parts of the furnace. Then the fixed carbon is completely consumed, and when the chain reaches the end of its travel the ashes are dumped and the chain kept clean and free from ash or clinker.

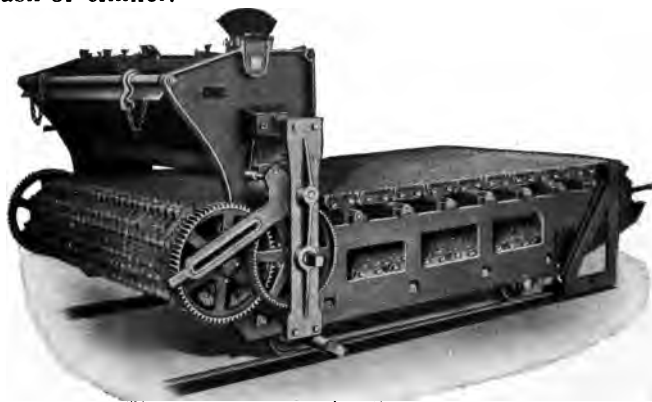


FIG. 27.

CHAIN GRATE STOKER.

A good idea of the construction and general appearance of the chain grate stoker may be obtained from Fig. 27. It will be noted that the whole device is

mounted on rollers running on a track, thus making it comparatively easy to remove the stoker from under the boiler in case extensive repairs are required. Small repairs like the replacing of broken links, can be made without removing the stoker and usually without even stopping it. Fig. 28 shows a front view of the stoker with the chain removed, and Fig. 29 a rear view.

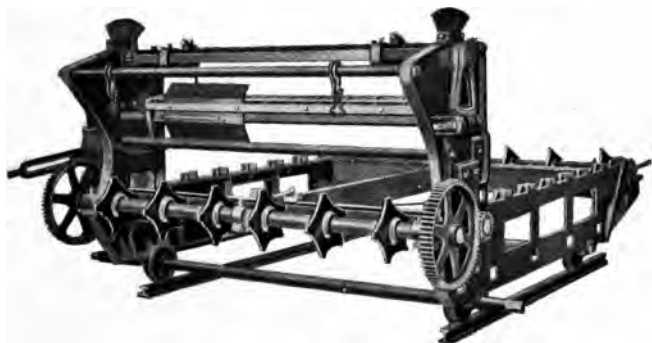


FIG. 28.

FRONT VIEW OF STOKER WITH CHAIN REMOVED.

In the design of a machine of this kind there are a number of important points to be considered if it is to give satisfaction under severe conditions of operation. In the first place, the frame upon which the chain is mounted must not be exposed too directly to the heat of the furnace, for it would warp and crack and would soon be destroyed. A glance at Fig. 27 will show that in the modern chain-grate stoker the side girders of the frame are removed a considerable distance from the fire, and they are also provided with large air spaces. This keeps the side girders cool and assists in providing a uniform supply of air to the underside of the chain, that is, beneath the fuel bed.

When such a stoker is subjected to hard and continuous service it is to be expected that a link will occasionally break or burn out and will have to be replaced by a new one. In the early designs the links were simply strung on a round rod, holes being provided in the links to receive the rod. This made the removal of a wornout link a rather troublesome job, since it could not be taken out without disturbing all the other links between it and the end of the rod. This involved stopping the stoker and possibly a shut-down of the boiler, for a short time at least. Fig. 30 shows the links used on the Green chain-grate stoker, by means of which this trouble is avoided. The links have slotted openings and the connecting bar upon



FIG. 29.
REAR VIEW OF STOKER WITH CHAIN REMOVED.

which they are mounted is oval in cross section. In a certain position this connecting bar will slip into the slot in a link, but when the bar is turned slightly it is locked in position and can not be removed. The



FIG. 30.
LINKS FOR CHAIN.

binder links are provided with holes instead of slots, and are placed one at each end of the connecting bars. Cotter pins are then applied to hold the binder links in place; these cotters and end links are shown clearly in Fig. 27.

With such an arrangement, when a link is to be removed it is only necessary to remove cotter pins and binder link, turn the connecting bar slightly and lift the link out. This operation can be done quickly, it being unnecessary in many cases to even stop the stoker, as already mentioned.

In the Green grate, in sizes exceeding 7 feet 6 inches in width, the chain surface is "double web." That is, the chain surface consists of two continuous sections, the connecting bars extending only half way across the total width of chain. This requires binder links in the middle of the chain, a special design being used which does not require the removal of the link in order to turn the connecting bar when some inside link is to be removed.

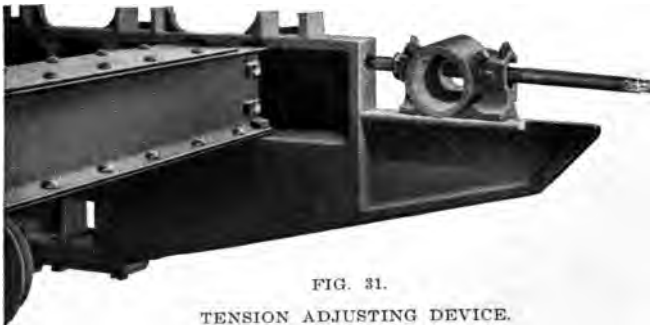


FIG. 31.

TENSION ADJUSTING DEVICE.

It is also very essential that chain tension be adjustable without removing the stoker from the furnace space. The method by which this is done may be seen from Fig. 29, and also more in detail from Fig. 31.

The adjusting screws are accessible from the rear while the stoker is in place.

The stoker is driven from an eccentric on a line shaft, placed either overhead or below the floor. The driving mechanism is shown from two different points of view in Figs. 32 and 33. It will be seen to consist



FIG. 32.
DRIVING MECHANISM.

of a ratchet operated by the rod from the overhead (in this case) eccentric; cast-steel pawls and cast-steel spur gear train. The whole is carried on an independent frame, bolted to the stoker frame. A study of Figs. 32 and 33 in connection with Fig. 27 will make plain just how the stoker is driven.

Fig. 34 shows the design of the sprockets which carry the chain. They are mounted on the front and rear sprocket shafts, Fig. 28 plainly showing the ar-

rangement. It will be noted that these sprockets are made scalloped between the teeth, the purpose being to insure the proper seating of the drive links of the chain upon the sprockets. This proper seating might not occur if the chain should reach the front sprockets covered with ashes accumulated during its return travel from rear to front sprocket shaft.

The thickness of full bed which the stoker receives is controlled by a regulating feed gate. It is supported from a square shaft shown plainly in Fig. 28, and



FIG. 33.
DRIVING MECHANISM.

moves up and down between vertical guides. The square shaft carries a sector on one end engaging a worm on the opposite side of the frame from the driving mechanism. In this way the gate may be

readily raised or lowered to vary the thickness of the fire. A lining of fire brick is used to protect the metal of the gate from the heat of the furnace. A frequent source of trouble with the feed gate has been the tendency of the fire to eat back into the coal hopper and



FIG. 34.
SPROCKET.

thus in time damage and destroy the gate. This trouble is now prevented in the Green stoker by placing removable shields on the gate in such a manner as to maintain a ventilated air space between the shield and the outside of the gate, thus protecting the latter from the heat. The shields extend below the bottom of the tile lining to protect it from injury, and thus the shields determine the thickness of the fuel bed. Details of the gate construction are shown in Fig. 35.

An important point in connection with the operation of a chain-grate stoker is the proper ignition of the fuel as it enters the furnace. Perhaps the most successful method at the present time is a flat ignition arch placed over the front of the grate. This arch re-

ceives heat from the fire and reflects it down on the incoming coal, thus raising the temperature until the volatile gases are driven off and the coke is ignited. A flat arch of this kind is much easier to build and maintain than a sprung arch, and being equally distant from the fuel all the way across the furnace it gives a uniform igniting effect.

Figs. 36 and 37 show the construction and method of support of a flat ignition arch designed and patented by the Green Engineering Company. Two channels comprise the main supporting frame; between these channels a number of I-beams are run, the latter supporting the special fire tiles as shown in Fig. 36. This



FIG. 35.
DETAILS OF REGULATING FEED GRATE.

method of construction removes all side thrust upon the side walls of the boiler setting, which is impossible with any form of sprung arch.

In connection with the chain-grate stoker the water back is an important feature. Fig. 39 shows a pressure

water back in position in the furnace. It will be seen to consist of two lengths of pipe connected together at one end, and at the other connected to the water space of the boiler. Thus the water back becomes a



FIG. 36

METHOD OF SUPPORTING FIRE TILE IN IGNITION ARCH.

part of the water circulation system of the boiler, water flowing through it at all times. The water back is placed just above the chain at the rear end, and under the overhang of the bridge wall. In this position it protects the bridge wall from the excessive heat of the furnace, and also adds to the heating surface of the boiler. It is not improbable that as much as one boiler horse-power is generated per square foot of water-back surface.

In order to get high furnace efficiency with a chain-grate stoker it is necessary to prevent the infiltration of excess air at all points, as indeed it is with any form of furnace. Leakage is very likely to occur at the end of the grate between the chain and the overhanging bridge wall. The water back helps to close up this space, but there must, of course, be enough free space to allow for the discharge of the ashes. In order to

make sure that no leakage of air will occur at this point a damper is placed below in such a manner as to effectually prevent the entrance of air. This damper is shown in the setting elevation, Fig. 38.

The chain-grate stoker described thus far is designed for use with free-burning, high-volatile coal. When low-volatile coals are to be used a somewhat different design is required. Fig. 40 shows the Green L Type Stoker, designed for this purpose. The chief difference between this stoker and the type already described is the inclined plate at the front, down which the coal is made to slide by a slight agitation of the plate. This serves to break up the coal and deliver it to the chain in a fragmentary condition. The tendency of this coal is to cake as the volatile is driven off and the agitation of the plate serves to prevent its forming in a more or less solid mass.

The chain-grate stoker in the forms described here has a wide application in steam boiler practice. With



FIG. 37.
METHOD OF SUPPORTING IGNITION ARCH.

a properly constructed furnace it can be operated without smoke and with high economy with very low-grade coal. The charges for stoker and furnace maintenance and repair are probably as low as for any other me-

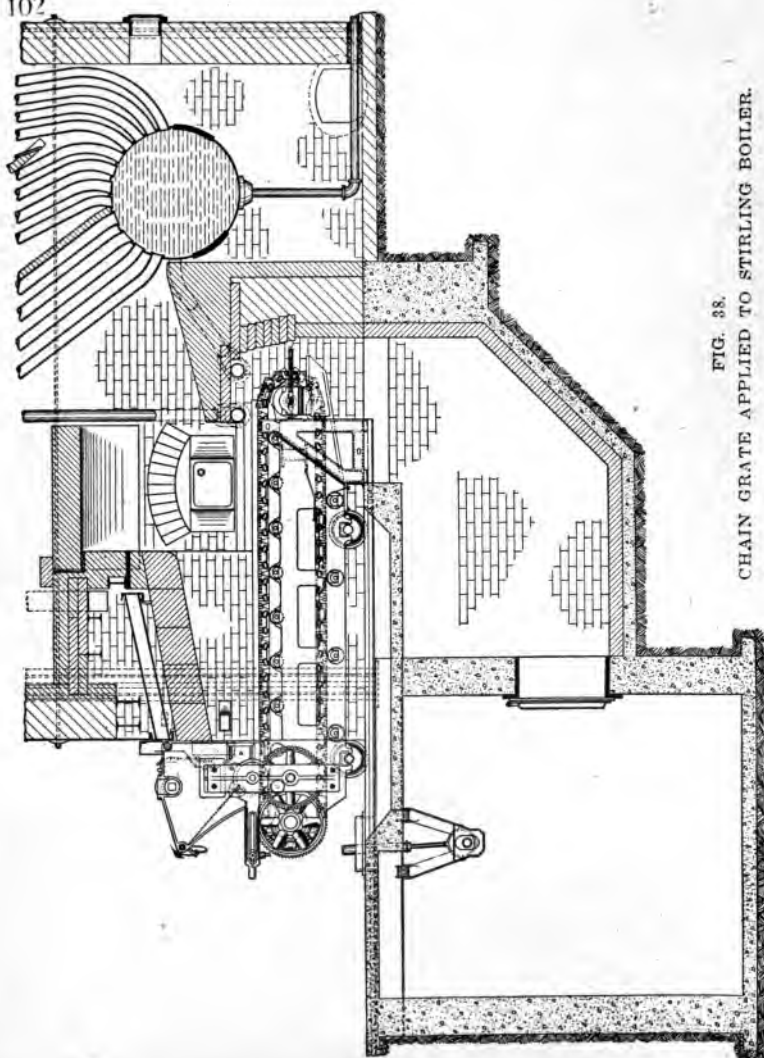


FIG. 38.
CHAIN GRATE APPLIED TO STIRLING BOILER.

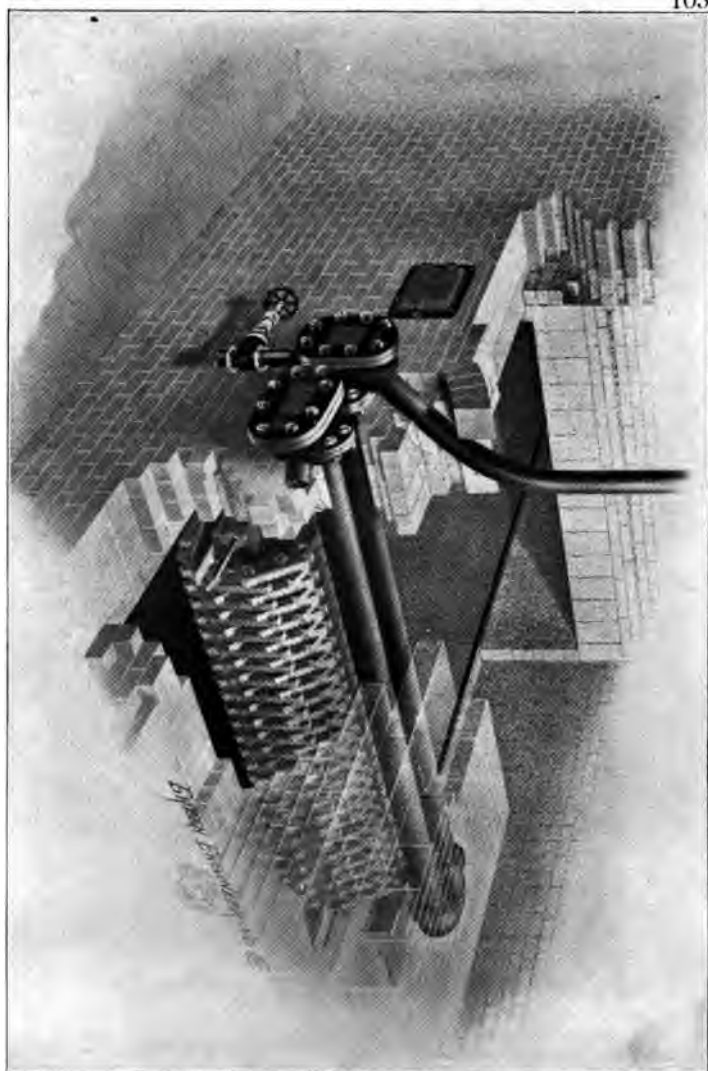


FIG. 39.
PRESSURE WATER BACK.

chanical stoker on the market, and lower than many. It adapts itself well to heavy overload conditions, with very little loss in efficiency. The increasing number



FIG. 40.
CHAIN GRATE STOKER FOR COKING COALS.

of these stokers in use indicates that it meets satisfactorily a wide range of conditions in steam-boiler practice.

Questions and Answers.

Q. What is one of the most important requirements for smokeless combustion?

A. A uniform distillation of the volatile gases from the coal.

Q. How is this best effected?

A. By a uniform rate of feed of the fuel to the furnace.

Q. Name one device designed for this purpose?

A. The chain-grate stoker.

Q. What is the essential part of the stoker?

A. A moving endless chain which carries the fuel into the furnace.

Q. How is this chain moved?

A. Power is supplied from an eccentric on a line shaft; the rod from the eccentric operates a ratchet and pawl which drive the stoker by means of a train of spur gears.

Q. Can the rate of travel of the stoker be changed?

A. Yes, the point where the eccentric rod is fastened to the ratchet is adjustable, which varies the travel of the pawl.

Q. How is the thickness of the fuel bed controlled?

A. By an adjustable gate at the front of the stoker.

Q. What is a water back?

A. A pipe placed at the back end of the grate in front of the bridge wall, through which water circulates.

Q. What is its purpose?

A. To protect the bridge wall and assist in sealing the rear of the furnace.

Q. What is an ignition arch?

A. A flat arch in the front of the furnace which helps to ignite the incoming coal.

CHAPTER X.

The Murphy Automatic Furnace.

The chain-grate stoker discussed in the previous chapter is perhaps the best known example of the front feed principle in automatic stoking devices. Another well-known and widely used method is that of the "side feed," in which the fuel is fed into the furnace from two magazines, one on either side of the setting. Perhaps the best known example of the side-feed principle in automatic stokers is the Murphy furnace.

A good idea of this furnace may be obtained from Fig. 41, which shows a transverse section viewed from the rear end. A similar view is shown in Fig. 42, in which more of the details of construction may be seen. This stoker will be seen to consist essentially of two inclined grates, one on each side of the furnace, the upper end being at the side and the lower end near the center. These grates are made up of two different kinds of bars arranged alternately. In Fig. 43 is shown the general appearance and design of these grate bars, one of which is stationary and the other movable. The movable bars are pivoted at their upper ends, and are given a rocking motion at their lower ends by means of a rocker bar. This gives them a motion alternately above and below the stationary bars and in this way the fuel bed is kept broken up and the movement of the coal down the incline is facilitated. It will be noted from Fig. 43 that the stationary grate bars are provided with ribs on both sides for the upper half, approximately, of their length. This is for the purpose of preventing the droppage of fine coal through the grate before the coking process is complete, and also

to exclude excess air at this particular point in the combustion process.

The method of feeding the coal onto these inclined grates is interesting, and may be seen clearly from Fig. 42. On either side of the furnace, and extending its entire length from front to back, is a coal magazine into which coal may be discharged by a down spout

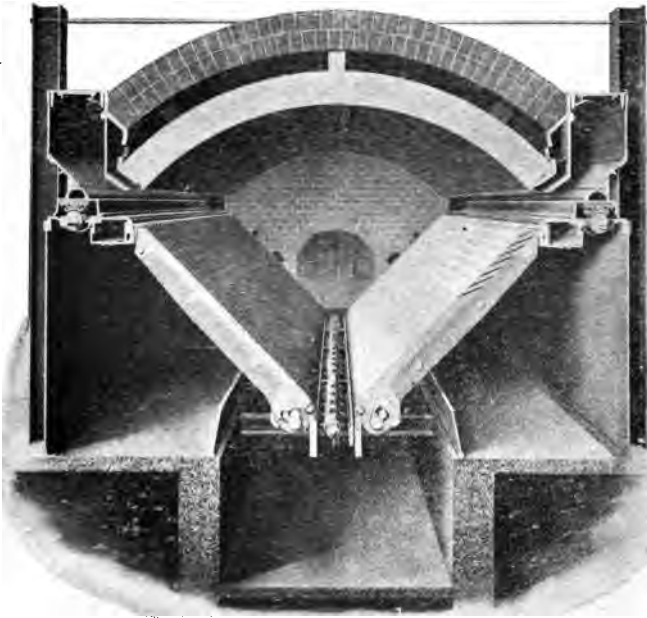


FIG. 41.

from an overhead bunker, or shoveled by hand. Just at the bottom of this magazine is the coking plate (see Fig. 42) upon which the coal is first discharged from the magazine. This plate furnishes the bearing for the

upper end of the grate bars, the movable bars turning on pins as shown in the figure. Below the coking plate is an air duct through which air is drawn from the front of the furnace and discharged at the back into the

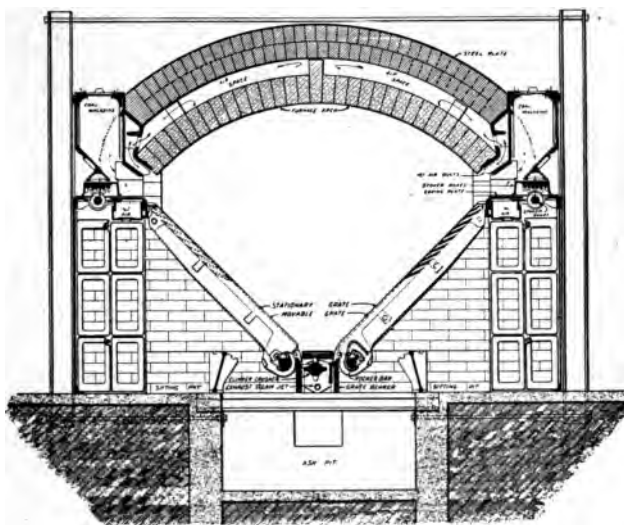


FIG. 42.

air chamber in the arch. This keeps the coking plate from becoming overheated, thus adding greatly to its length of life.

The stoker boxes are for the purpose of pushing the coal from the magazine out onto the coking plate. They are shown in Fig. 42 and also more in detail in Fig. 44. These boxes are moved back and forth by means of segment gears and racks, the gears being mounted on the stoker shaft which is driven from an outside source of power. The reciprocating motion of the stoker boxes produces the feed of the fuel, and can

be regulated to suit the character of the coal and the rate of combustion.



FIG. 43.

The lower ends of the grate bars are supported on two heavy plates known as the "grate bearers," one for each side of the furnace. These grate bearers are supported on I-beam cross girders, as shown plainly in Fig. 41. In addition to carrying the lower ends of the grate bars, they furnish a support for the rotating clinker grinder. The latter may be single as shown in Fig. 45, or double, as shown in Fig. 46.

This clinker grinder consists of a square steel shaft upon which are placed small toothed cast-iron segments. The latter may be easily and cheaply renewed in case of wear or breakage. As its name implies, the function of the clinker grinder is to break up the large lumps of ash and clinker which might otherwise clog

the furnace, and discharge them into the ash pit below. Just below the clinker grinder is a small perforated pipe connected with the exhaust from the stoker engine.

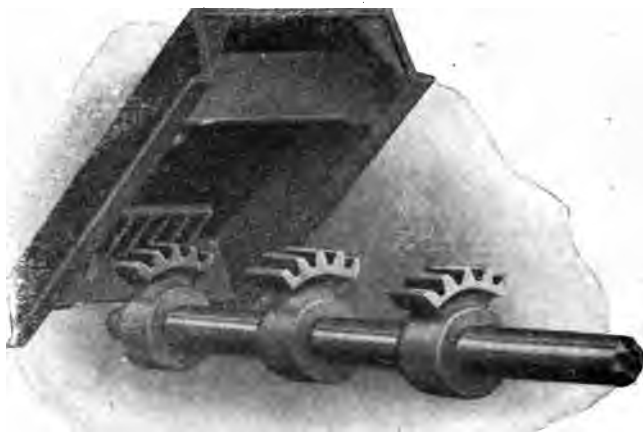


FIG. 44.

gine. This pipe is shown plainly in the longitudinal section of the furnace. Fig. 47. The exhaust steam emitted directly beneath the clinker grinder serves to soften the clinker and so assist in the cleaning process. The rate of feed of the grinder is adjustable, so that it can be varied to suit the amount of ash in the coal.

An important feature of this furnace is the double sprung arch. The arch is supported at each side of the furnace on the arch plate shown in detail in Fig. 48. It will be noted that on this arch plate are cast a number of ribs which form a series of air ducts immediately under the arch and over the coking plate. The manner in which the arch is sprung from the arch plate, and also the air ducts just below the arch, are shown plainly in Fig. 41. Further details are shown in Fig. 49.

The lower arch is built of special fire brick, varying in thickness from 6 inches to 12 inches according to the size of the furnace. Above this fire-brick arch is an air space from $3\frac{1}{2}$ inches to 5 inches in thickness. It was stated above that air from the duct under the coking



FIG. 45.

plate is discharged into this space in the arch. Here it is heated by the radiant heat from the furnace, and



FIG. 46.

finally discharged through the ribbed arch plate, over the coal on the coking plate. This supply of hot air

being discharged over the coal during the coking process greatly assists in the combustion of the volatile gases. It is because of this feature that the Murphy furnace can be operated practically without smoke.

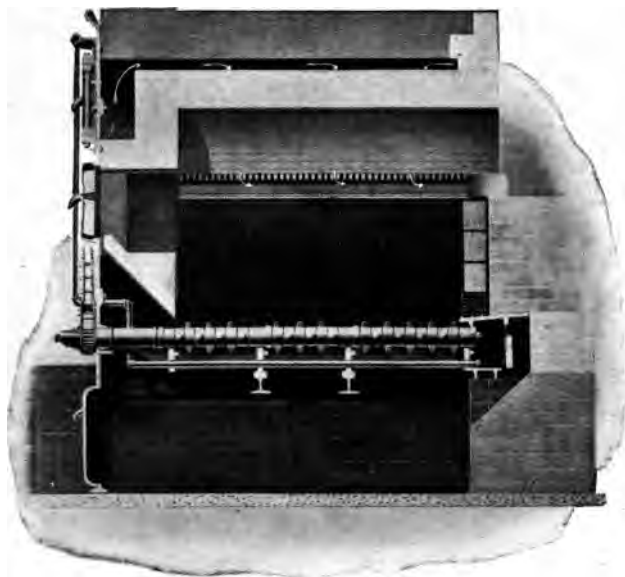


FIG. 47.

The upper arch is really a double arch of common brick, and over this is placed a steel covering, rolled to conform with the curve of the arch. In such a construction as this the furnace requires no side walls but is enclosed instead in sheet steel sides which the makers supply with the furnace.

In the operation of this furnace there are five shafts or bars which must be given an oscillating motion, as

follows. Two rocker bars, two stoker shafts, and one clinker grinder. In the case of a double clinker grinder this becomes six instead of five. The power to operate these shafts is supplied by a reciprocating bar across the front of the furnace. This is a heavy forged steel bar to which the operating parts are connected by



FIG. 48.

means of links. The construction and arrangement of parts is shown in Fig. 50, which shows the Murphy furnace applied to a horizontal tubular boiler. The operating links can be adjusted or removed at any time, so that one furnace of a battery may be thrown out of service without interfering with the others.

The reciprocating bar which operates the furnace may be driven directly from a small stoker engine as shown in Fig. 51, or if convenient an electric motor may be substituted for the engine.

In the operation of this furnace, as the coal leaves the magazine it is fed alternately and intermittently onto the coking plate by the action of the stoker boxes.

It rests for a short time on the coking plate, where the volatile gases are distilled. These gases are then mixed with hot air which is being discharged from the ducts in the arch plate. This forms a readily combustible mixture, all the requirements for complete combustion being present. Thus the volatile part of the coal is consumed without the formation of smoke.

The fuel next passes out onto the inclined grates where it receives the necessary amount of air coming through the grates from below. When the carbon is practically all consumed and the lower end of the grate bars has been reached the motion of the moveable bars tends to prevent the formation of large clinkers. In as much as these bars are pivoted at their upper ends they have their greatest motion at the lower ends, where the motion is needed to assist in the prevention of large clinkers. When the bottom of the grate has been reached the ash and clinker are received by the clinker grinder and reduced to small size, after which they are dropped through to the ash pit below.

This furnace is usually installed by the makers to give its best efficiency at from 100 to 150 per cent of boiler rating. This, however, by no means represents the limit of capacity of the furnace. As much as 200 per cent of boiler rating may be secured with but little loss in efficiency. The question of high efficiency at high rates of working is very largely one of the proper proportioning of furnace and draft. In fact, with a good grade of coal and sufficient draft there seems to be no reason why this furnace can not be operated at a capacity close to the maximum ability of the boiler to absorb heat.

Questions and Answers.

Q. To what class of automatic stokers does the Murphy Furnace belong?

A. To the side feed class.



FIG. 49.

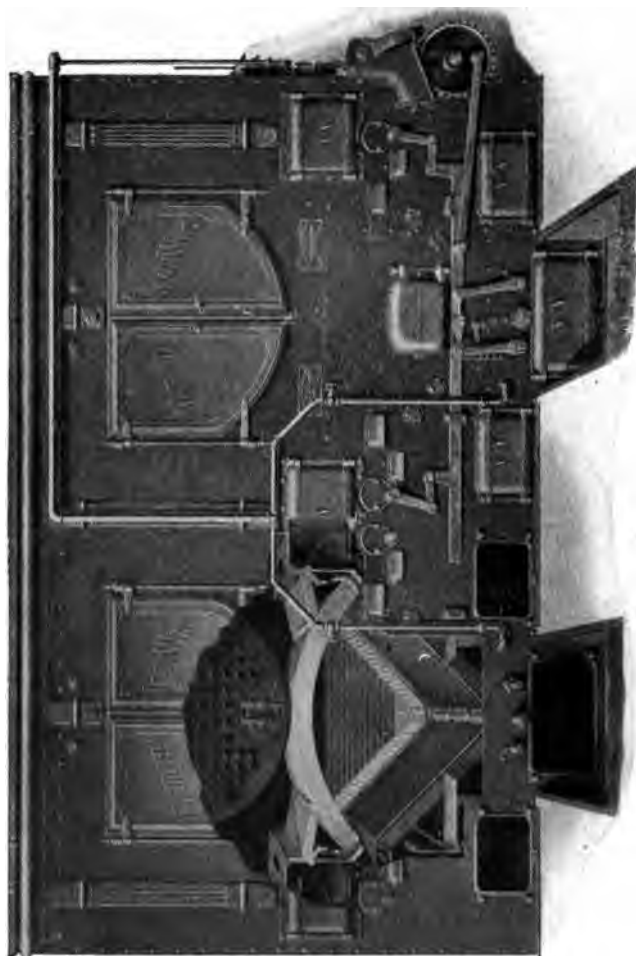


FIG. 50.

Q. Of what does the chief part of this furnace consist?

A. It consists of two grate surfaces, inclined from the side and meeting in the middle of the furnace.

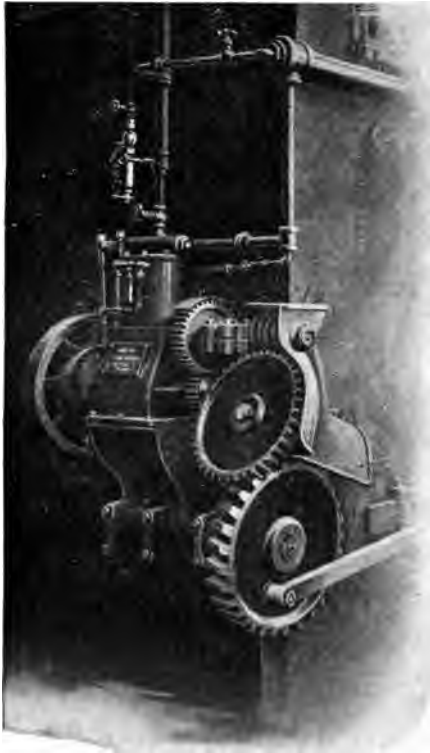


FIG. 51.

Q. How many kinds of grate bars are used?

A. Two kinds, stationary and movable.

Q. How are the movable bars placed in the furnace?

A. They are pivoted at their upper ends and given a rocking motion at their lower ends by means of two rocker bars.

Q. Where is the coal supply fed to the furnace?

A. Into two magazines, one on each side.

Q. What is the coking plate?

A. A flat plate at the bottom of the coal magazine upon which the coal is discharged.

Q. How is the coal fed to the coking plate?

A. By means of the stoker boxes, operated by segment gears and racks.

Q. What is the clinker grinder?

A. It is a heavy steel shaft on which toothed cast-iron segments are placed, to break up the clinker.

Q. Where is the clinker grinder placed?

A. At the bottom of the inclined grates at the center of the furnace.

Q. What kind of an arch is used in this furnace?

A. A double arch, sprung between the sides of the furnace.

Q. What is the object of the airspace in the arch?

A. To heat air to assist in the combustion of the fuel. It also makes a better arch.

Q. How is the furnace operated?

A. By a reciprocating bar across the front, driven by a small stoker engine.

CHAPTER XI.

The Jones Under-feed Stoker.

In our discussion of mechanical stokers nothing has been said thus far of the under-feed principle. It consists essentially in feeding the coal in at the bottom of a retort in which it rises gradually to the combustion zone at the top. As the coal rises to the top of the retort its temperature rises gradually, the vola-



FIG. 52.

tile gases being distilled in the process. These gases must then rise through the fire at the top when complete combustion takes place. Finally the coal itself, which by this time has been reduced to coke, reaches the surface and is burned.

Perhaps the best known example of this principle is the Jones Under-feed Mechanical Stoker. In Fig. 52

is shown a view of the fuel retort, which is the only part of this stoker which is inside the furnace and therefore in contact with the fire. This retort can be made heavy and durable, and since there are absolutely no moving parts to come into contact with the fire, the maintenance charges on a stoker of this kind are extremely small.



FIG. 53.

It will be seen from Fig. 52 that there is a small rod in the bottom of the retort, upon which are mounted two rectangular shaped lugs. This rod is known as the auxiliary pusher rod, and is given a reciprocating motion from the main ram, which will be described later. This auxiliary pusher is for the purpose of securing a more even distribution of the fuel within the furnace, after it has been delivered to the retort by the main ram.

The Jones Under-feed Stoker is used entirely with forced draft, and so in this particular also it differs greatly from any stoker discussed thus far. The air for combustion is supplied through tuyere blocks which are placed at the top of the retort and on both

sides. Hence the air passing through these tuyere blocks blows from both sides toward the center of the fire, and can at all times be adjusted exactly as the rate of combustion may require. The manner in which



FIG. 54.

these tuyere blocks are attached to the retort is shown clearly in Fig. 53. It will be noted that each tuyere block is provided on its under side with a hook or eye-hole, similar to an eye-bolt. When all the blocks are in place a rod is run through all the eye-holes, and the tuyere blocks are thus held securely in place. Replacing one of these blocks which may have become worn or broken is a simple operation and fairly inexpensive. A good view of the tuyere blocks in position in the complete stoker may be seen from Fig. 54.

That portion of the stoker which is outside of the furnace is shown in Fig. 55. It consists of the cylinder, the ram case, and the coal hopper. The ram case is bolted securely to the retort, the two being joined together at the boiler front. This case contains the main ram, the purpose of which is to take the coal as it flows down from the hopper and push it forward into the retort in the furnace. This ram is driven by a steam piston contained in the cylinder shown at the

right-hand side of the illustration in Fig. 54. This piston is usually about 12 inches in diameter and has a stroke of approximately 14 inches. It has a recip-



FIG. 55.

rocating motion similar to the steam piston of a direct-acting pump, this motion being controlled by specially designed automatic valves.

Fig. 56 shows a section through the Jones stoker, from which a good idea of its construction may be obtained. The steam piston and main ram are clearly shown, as well as the auxiliary pusher rod in the bottom of the retort.

Fig. 57 shows the Jones stoker applied to a horizontal return tubular boiler. The air duct supplying air to the chamber below the fire is shown plainly in this view. Also it will be noted that on either side of the furnace, and extending from the retort to the side wall, there is a dead-plate. The fire spills over from the retort onto these dead-plates, and they also serve to catch and hold the ashes until they are removed.

The automatic features of the Jones stoker are particularly interesting, and merit special attention. It was stated in an early chapter that the rate of supply of **both fuel and air** must be carefully proportioned at all times to the demand for steam, that is, to the rate



FIG. 56.

of combustion, if high furnace efficiency is to be maintained. This is just what the Jones stoker does, and for this reason it is able to show good economy at widely varying rates of working and particularly at light loads, a feature not possessed by any of the stokers discussed thus far.

The fan which supplies air to the furnace is driven by a special vertical engine which is equipped with a regulating valve. Whenever the steam pressure rises above a certain amount the regulating valve throttles the steam supply and thus slows down the engine. If the steam pressure falls too low the regulating valve opens up and admits more steam to the engine, thus increasing its speed. In this way the amount of air supplied to the furnace is proportioned to the demand for steam.

The rate at which the fuel is fed to the furnace is also made proportional to the demand for steam by the following method. It will be remembered that the ram which forces the coal into the hopper is actuated by a steam-driven piston working in a cylinder similar to

that of a direct-acting steam pump. Now the admission of steam to this cylinder is controlled by a rotary disc valve, a separate admission valve being required for each stoker cylinder. Fig. 58 shows a bank of four of these disk valves, piped up ready for connection to



FIG. 57.

steam and exhaust lines. The frame carrying these valves is placed near the blower which supplies the air to the furnace. The valves are rotated by means of a belt running on a pulley on the blower shaft, the relative sizes of blower pulley and valve pulley being so adjusted as to maintain the proper relation between air

supply and fuel supply. The disk valves control the amount of steam admitted to the stoker cylinder, and thus the rate of motion of the main ram is controlled. If the steam pressure falls, the regulating valve causes the blower engine to speed up. This increases the



FIG. 58.

speed of the blower and more air is delivered to the furnace. At the same time the rotary disk valves are driven faster, more steam is admitted to the stoker cylinder, the ram moves faster, and more coal is supplied to the furnace.

When the steam pressure rises above the desired point just the reverse takes place, and the rate of com-

bustion is reduced. In this way both fuel supply and air supply are controlled automatically, and thus efficient conditions are maintained at all times.

The stoker cylinder receives steam throughout the whole stroke of the piston, no earlier cut-off being provided for by the rotary valves. A moment's consideration will make it evident that it would not be practicable to use the steam expansively in service of this kind. When the ram begins its forward stroke the first few inches of its travel simply serve to pack the coal firmly together in the throat of the ram case. Then as the motion continues the whole charge is pushed forward into the retort, the fuel already there being displaced upward. It follows therefore that the heaviest load on the ram is near the end of the stroke, and hence the piston must receive full steam pressure for the whole stroke, inasmuch as there is no fly-wheel to carry it past this point of greatest load.

Fig. 59 gives a good view of an installation of Jones stokers, showing boilers, stokers, blower engine, blower, and rotary disk valves. The space in front of the boilers occupied by the stoker cylinder, ram case, and hopper, is not large, being about 4 feet 8½ inches in length outward from the boiler front, and 17 inches in greatest width.

The operation of the Jones Under-feed Stoker is extremely simple, and at the same time shows a high degree of efficiency. The coal is fed into the hopper either by hand or from a downspout from an overhead bunker. Any fair grade of coal burns well in this stoker, provided it is small enough not to choke the throat of the ram case, which is about 8 inches in diameter. The ram receives the coal from the hopper and pushes it forward into the retort. The auxiliary pusher rod in the bottom of the retort agitates the fuel therein, and causes it to work upward toward the surface. As the coal nears the surface the volatile

gas is gradually driven off by the heat of the fire, and burned as it passes through the fire. Finally the coal reaches the surface where combustion is completed.

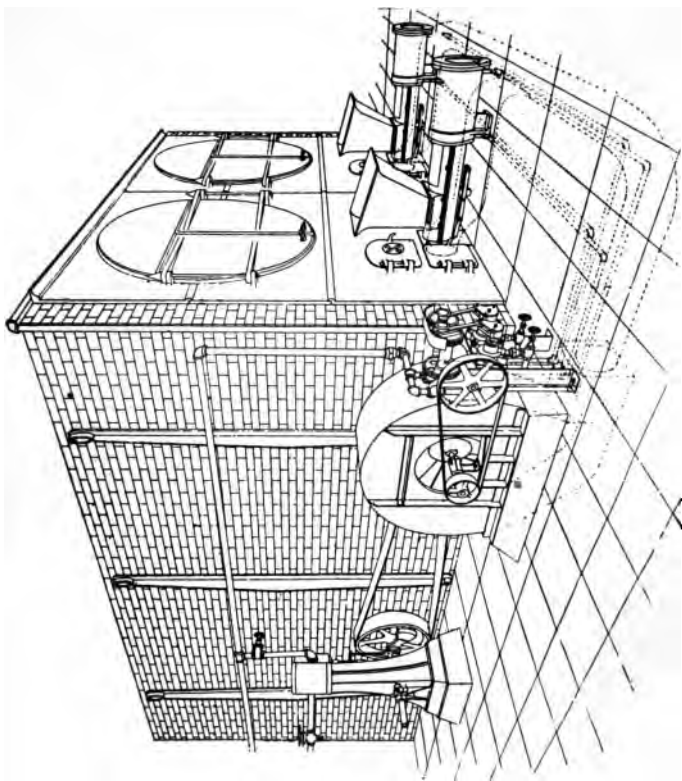


FIG. 59.

In the usual form of Jones stoker, the ashes are allowed to collect on the dead-plates on either side of the retort. They are then removed by hand, being pulled out at two doors in the front of the setting.

Fig. 60 shows the appearance of a boiler front equipped with Jones stokers. The two upper doors shown in the figure are for the purpose of removing the ash and clinker. A recent improvement to this stoker provides a mechanical arrangement for agitating and cleaning the fires and removing the ashes. In this form the

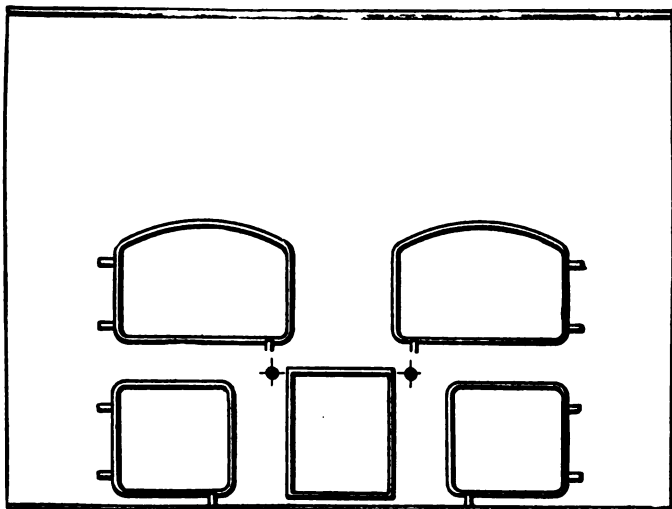


FIG. 60.

stoker is entirely automatic, the only attention which it requires being directed to the removal of the ashes from the ash-pit.

In summing up the points of superiority characteristic of this stoker, it should be noted first of all that it possesses all the advantages of mechanical forced draft. This consists chiefly in a nice adjustment between air supply and rate of combustion. This adjustment is made automatically and practically instantaneously, so that no matter what the load fluctua-

tions may be, the proper draft is always maintained. The automatic control of the fuel supply insures economical adjustment at all times and leaves almost nothing to be desired in the way of automatic furnace control. In this particular the Jones stoker is the equal, if not the superior, of any other furnace which has come to our attention.

The combustion is such that no fire-brick arches are required to render the furnace practically smokeless. The coal rises in the retort like a slow-moving fountain, the gases being distilled as the coal reaches the surface. As they pass through the fire, they are thoroughly mixed with the proper amount of air at a high temperature, which as we have seen in an early chapter, is all that is required for smokeless combustion. The absence of all arches makes an economical furnace to build and maintain. There is probably little doubt that the Jones stoker in the form described here, will have as low maintenance charges as any mechanical stoker on the market.

Questions and Answers.

- Q. What principle is used in the Jones stoker?
- A. The under-feed principle.
- Q. What are the chief parts of the Jones stoker?
- A. The retort, ram case, ram and stoker cylinder.
- Q. Which of the above parts are inside the furnace?
- A. The retort.
- Q. How is the coal fed into this retort?
- A. By a ram actuated by a steam-driven piston.
- Q. How is the air supply provided for this stoker?
- A. By a blower driven by a special engine.
- Q. How is the speed of this engine controlled?
- A. By a regulating valve, which in turn is controlled by the steam pressure.

Q. How is the speed of the piston which drives the main ram controlled?

A. By rotating disk valves driven from a pulley on the blower shaft.

Q. Are both air supply and coal supply controlled automatically?

A. Yes.

CHAPTER XII.

The Ignition Arch.

In the course of the preceding pages frequent reference has been made to the firebrick arch in a boiler furnace. It has been shown that such an arch assists to a considerable extent in securing smokeless and efficient combustion by providing a roof of refractory material for the furnace, and so preventing the volatile gases from the coal from coming into contact with the boiler heating surfaces until combustion has been completed. In the present chapter the firebrick arch will be considered somewhat more in detail, with a view to making clear the principles underlying its action.

For our present purpose it will be well to divide all boiler furnace arches into two general classes. First, the ignition arch, the chief function of which is to assist in the ignition of the fresh coal as it comes into the furnace. Second, the deflecting arch, the function of which is to deflect the burning gases away from the boiler heating surfaces, and at the same time to assist in the proper mixing of gases and air so as to promote complete combustion. It will be evident that both kinds of arches have an important part to play in the solution of the problem of efficient combustion.

The ignition arch has undergone quite radical changes in design within the last few years, the changes being prompted by a better understanding of the principles underlying its action. In the early designs the ignition arch was often made as short as two feet; a length of three feet was considered quite

generous, while an ignition arch four feet in length was regarded as extreme. These arches were built flat, with a slight upward pitch toward the rear, and were set quite close to the grate. These early designs located the arch entirely with reference to its distance from the grate, without regard to the thickness of fuel bed that would have to be carried. The result was

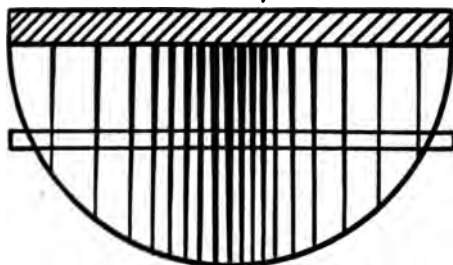


FIG. 61.

that those arches were frequently only two or three inches above the fuel when a thick fire was carried. Present practice places an ignition arch with reference to its distance from the surface of the fuel bed, in which case the character of fuel and average thickness of fire must be carefully considered when designing the arch.

The action of the short flat ignition arch just described was probably about as follows: The volatile gases liberated from the coal ignited at the surface of the fuel bed. The heat liberated by this combustion heated the arch immediately above to a state of incandescence, and the hot arch in turn reflected the heat back again onto the incoming fuel. In this way a prompt ignition of the fresh coal was effected, the arch acting as a mirror to reflect the heat forward to the point where it was most needed.

Experience with ignition arches has taught engineers that the greatest intensity of radiation is in a direction perpendicular to the radiating surface, and from its center. Also, the temperature produced at any point in the green fuel bed by the action of the

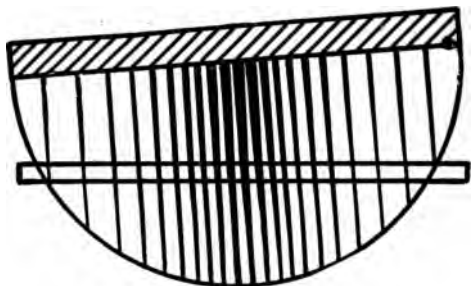


FIG. 62.

radiant energy from the arch is inversely proportional to the distance from the arch. That is, the farther a

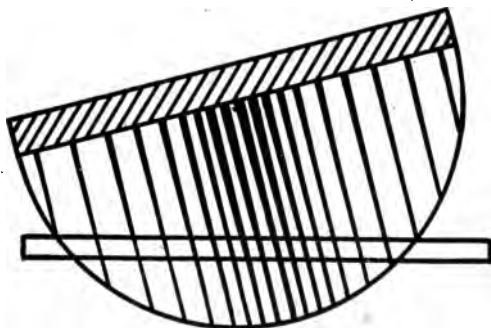


FIG. 63.

given point is from the arch the less heat it will receive.

If a flat arch be placed parallel to the grate it follows from the principles just stated that the maximum radiation and hence the maximum igniting effect will

be directly under the center of the arch. Fig. 61 shows the distribution of radiant heat under such an arch, the semicircle showing the character of the distribution, and the shading the intensity of radiation. Fig. 62 shows how the point of most intense radiation is thrown forward when the arch is tilted upward toward the rear, and Fig. 63 shows how the radiation is reduced and thrown still farther forward in the furnace when the arch is inclined still more.

An arch of this kind will give an igniting effect across practically the whole of the furnace, and although the figures show that this effect is greatest at the center, still the radiation from the side walls assists ignition at the sides, so that a flat arch gives practically uniform ignition across the entire width of the furnace. The figures show further that in order to get the maximum igniting effect near the front of the furnace where it is most needed the arch should be horizontal, or at least should have but a slight upward incline toward the rear.

When a sprung ignition arch is used the igniting effect is not so satisfactory in general as it is with the flat arch. The center of the arch being farther from the fuel bed than is the case with the sides of the arch, the igniting effect is greater at the sides of the furnace than at the center. The radiation from the side walls also tends to increase this discrepancy, so that even although the curvature of the arch may be slight the igniting effect is not uniform across the furnace. In view of this fact there seems to be no reason why the flat arch should not displace the sprung variety wherever the conditions make it possible, particularly when the mechanical difficulties in the way of the construction and maintenance of a sprung arch are considered.

From the foregoing discussion it should be evident that the short ignition arch, whether flat or sprung, merely takes heat from the burning volatiles and de-

flects that heat forward onto the green incoming fuel. In general the flat arch is to be preferred to the curved one because the ignition is more uniform across the furnace with the former. Later experience with the ignition arch has demonstrated the possibility of using the heat from the rear of the fuel bed for purposes of ignition. At this point in the furnace the fixed carbon of the coal is being consumed and it is here that the greatest amount of heat is liberated, and hence the highest temperatures exist.

In order to utilize this heat from the rear of the furnace a radical change was made in ignition arch design. This change consisted chiefly in making the arch very much longer than before, lengths of six to eight feet being not at all uncommon. The action of such a long arch is almost exactly like that of a mirror, reflecting heat from the rear of the furnace to the front. Keeping in mind the well known law of reflecting surfaces that the angle of incidence is equal to the angle of reflection, it is possible to calculate the length and position of an arch for any particular furnace, provided the characteristics of the fuel and the load conditions are known accurately.

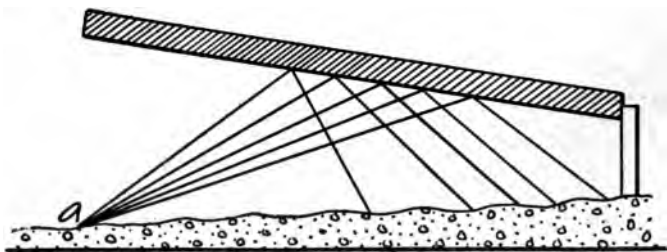


FIG. 64.

Fig. 64 shows how heat coming from a point "a" in the rear of the furnace is reflected by the arch to various points in the front of the furnace. The arch

shown is flat and inclined upward toward the rear of the furnace. This pitch is usually not more than three inches to the foot and in many cases it is less. In fact, with certain kinds of coal a horizontal arch six or seven feet long may be used to good advantage. Fig. 65 shows how the heat is reflected by a horizontal arch from the rear to the front of the furnace.

Let us now consider a few features of ignition arch design as affected particularly by the kind of fuel which is to be used. Consider first of all a clean free-burning bituminous coal, fairly low in ash and containing thirty per cent of volatiles. Such a coal will ignite with comparative ease, and will burn out free from clinker or other troublesome ash. If such a coal

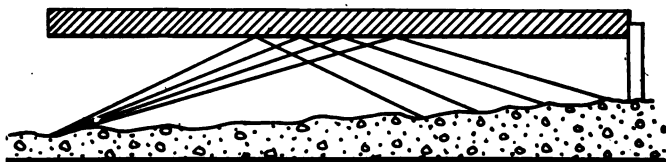


FIG. 65.

is to be burned on a chain grate or similar stoker, the arch should be designed as follows:

Inasmuch as the fuel ignites easily, the igniting action may properly be confined to a comparatively narrow zone at the front of the furnace. If the stoker is approximately ten feet long the arch need not be more than six feet in length. It should be set about fifteen inches above the grate at the front, which will give a space ranging from five to ten inches between fuel and arch. The arch should have a pitch of about $2\frac{1}{2}$ or 3 inches to the foot, inclining upward toward the rear. The reason for the pitch of the arch is to provide an increasing furnace cross-section from front to rear, so as to handle the increasing volume of furnace gases without undue restriction.

Consider next a coal containing as high as 20 per cent to 30 per cent of ash, having a high moisture content, and possibly in the neighborhood of 20 per cent of volatiles. Coals similar to this are found in many of the western States and are now being burned successfully on chain grate stokers. Such a fuel will ignite much less readily than the first one considered, and for this reason the igniting action must be continued over a much wider zone than before. Also, the front of the furnace must be maintained at as high a temperature as possible, to assist the ignition. For this reason the hot gases must not pass so readily from the furnace, but must be "bottled up" by restricting their path somewhat.

Assuming the same size of furnace as before, an arch to burn this fuel successfully should be about $7\frac{1}{4}$ feet long, not more than 11 or 12 inches above the grate at the front, and should have only a slight upward pitch toward the rear. The action of this long, almost horizontal arch will be to reflect heat from the rear of the furnace over a zone of considerable width in the front. Thus the igniting effect of the arch will be continued for a considerable time after the fuel enters the furnace, a necessary condition for satisfactory burning of such coal, particularly at high rates of combustion and high speed of grate travel.

The arch being set almost parallel with the grate, the heated gases do not have such a ready escape from the furnace as when the arch has considerable pitch. Being retained for a time in the furnace in this way, these hot gases raise the temperature of the entering coal, and thus assist ignition.

Consider as a third example, the case of certain coal found in some of the southwestern States, particularly Texas. This coal contains 50 per cent or more of ash-forming materials, and at one time was considered practically useless for steam-making purposes. It is

extremely slow and difficult to ignite, and would seem to be almost "impossible" when used in connection with a mechanical stoker of the "progressive combustion" type.

To ignite such a coal successfully requires an arch just as long as the size of the furnace will permit. The limit to the length is imposed, of course, by the fact that sufficient space must be left between the end of the arch and the bridge wall for the escape of the furnace gases. The arch should be horizontal and set only about 10 or 11 inches above the grate. Such an arch will give an extremely wide ignition zone in the front of the furnace, and will "bottle up" the hot gases to such an extent as to assist materially in maintaining a high furnace temperature, particularly near the front. To operate a furnace designed in such a manner as this will, of course, require a good draft on account of the restriction at the furnace throat. But it is the only design of furnace which makes it possible to burn fuel of this kind on a mechanical stoker, and it really represents a long step forward in furnace design to meet a particular set of conditions.

From what has been said it should be apparent that the long ignition arch, set comparatively low, and either horizontal or with a pitch toward the rear not to exceed 3 inches to the foot, is as correct in principle as it has proved successful in operation.

Questions and Answers.

Q. Into what two general classes may furnace arches be divided?

A. Into deflection arches and ignition arches.

Q. What is an ignition arch?

A. A firebrick arch placed over the front of the furnace to reflect heat on the incoming coal.

Q. How long should this arch be?

A. Early design made it only 3 or 4 feet long, but it is now made as much as 6 to 8 feet long in a furnace 10 feet long.

Q. How should the arch be placed with respect to the grate?

A. About 10 to 15 inches above the grate, and either parallel to it or with a slight pitch toward the rear.

Q. How much should this pitch be?

A. Probably not to exceed 3 inches to the foot.

CHAPTER XIII.

Breeching and Chimney.

It may sometimes happen that a well designed furnace, properly operated, will fail to give satisfactory capacity or efficiency. In such a case it is often necessary to look for the trouble outside of the furnace itself.

One very important part of a boiler room installation, and one which frequently receives much less attention than it deserves, is the breeching through which the furnace gases pass from the boiler setting to the chimney. Unless this breeching is intelligently designed and carefully constructed it may cut down the capacity and economy of the furnace to a considerable extent.

The cross section of the breeching is perhaps the first point to receive consideration. It should be designed with reference to the total volume of furnace gases which it will be required to handle, rather than as a function of the grate area served. An approximate rule for the size of a breeching, and one which has frequently been used as a guide at least, is to make the section of the breeching about $1/6$ that of the grate served. But this rule takes no account of the kind of fuel which is to be used, nor the rate of combustion, the latter varying over a wide range in different plants.

Evidently if the character of the fuel which is to be used is known, and if the maximum load which the boilers will be required to carry, as well as their approximate efficiency is known, the amount of fuel

required per hour, and the amount of air needed per pound of fuel, can be predetermined with a fair degree of accuracy. Thus the weight of furnace gases produced per minute or per second, can be estimated, and if the breeching temperature be taken as 400° F. to 500° F. according to conditions, the volume of gases passing through the breeching per second can be calculated.

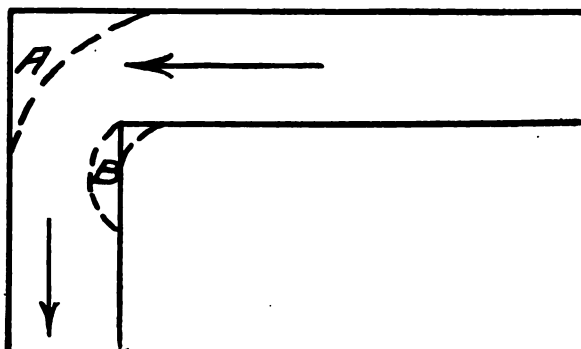


FIG. 66.

It is well to make the breeching of such a size that the velocity of gas flow will not exceed 35 feet per second. If the velocity exceeds this amount the friction of the gases against the wall of the breeching causes a drop in draft pressure which for a long run of breeching may become quite serious.

This matter of draft pressure loss depends not only on the size of the breeching but also upon its shape, length, number and character of bends, material of construction, etc. Experience has shown that a circular section gives less draft loss than a square or rectangular section, other conditions being the same. This is probably due to the fact that any fluid meets with less frictional resistance when flow-

ing through a pipe of circular section than in any other shape.

The draft loss due to length is practically proportional to the length for any shape of section. Hence it follows that not only from considerations of economy in first cost, but also to produce economy of operation, a plant should be laid out with just as short a run of breeching as conditions will permit. In a well designed breeching the draft loss will probably not exceed 0.1 inch of water per 100 feet of straight run.

The number of bends in a breeching should be kept as few as possible, because at each one there is an appreciable loss in draft pressure. A single right-angle bend will cause a draft loss of about 0.05 inch of water, due to the eddies formed in the gas flow when striking the turn. Figure 66 shows a plan view of a breeching in which there is a right angle bend. The gases flowing from right to left as shown by the arrow strike the bend at the point A with a certain amount of momentum, due to their weight and velocity. The flow of the gases is retarded and a "swirl" or eddy is formed, which causes a loss in draft pressure. The effect of the eddy is similar to a restriction in the breeching, because at the point B there is practically no gas flow. If it be considered in this way it is comparatively easy to see how a loss in draft pressure occurs. This effect can be reduced to a considerable extent by using a long radius bend as shown by the dotted lines. But a bend of this kind requires more space which in many city plants is not to be had. In such a case the draft loss due to a right angle bend must be put up with, and sufficient height added to the stack to compensate for the loss.

Breechings are usually made of steel or brickwork, and sometimes possibly of concrete. From

the point of draft loss an all steel breeching is probably to be preferred, but it should be well lagged or covered with an insulating material to prevent radiation and infiltration of air. This is an important consideration, because the chimney draft depends upon the temperature of the gases therein, and if they are cooled while passing through the breeching the draft will be reduced.

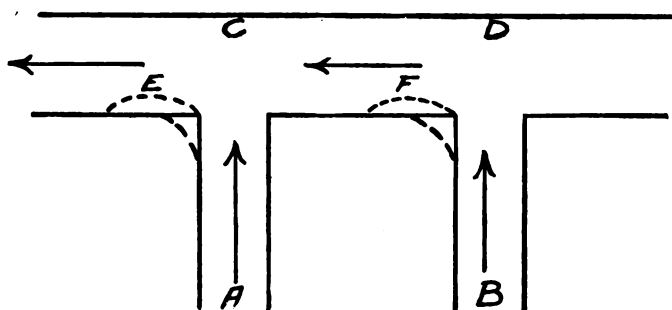


FIG. 67.

In the case of a comparatively long run of breeching into which the uptakes from two or more boilers discharge, the manner in which the connection between uptake and breeching is made has an important bearing on the draft loss. In figure *67 is shown an elevation of a breeching into which two uptakes discharge at right angles. Unless the corners are relieved somewhat practically the same action will take place as in a right-angle bend, Figure 66. The gas from uptake A will strike the opposite wall of the breeching at C, and the gas from B will strike at D. The result will be the formation of eddies with comparatively quiescent portions at E and F. As was described in connection with Figure 66 this restricted portion reduces the effective breeching area and a loss in draft pressure takes place at that point.

The draft loss which takes place at these points can be remedied somewhat by relieving the corner on the side of the uptake towards which the gas is to flow. Thus if the corners be extended as shown in the dotted curves, the gases will be deflected somewhat to the left and no quiescent pocket will be formed at E or F.

Conditions sometimes make it necessary to place the chimney out of the line of the breeching. In

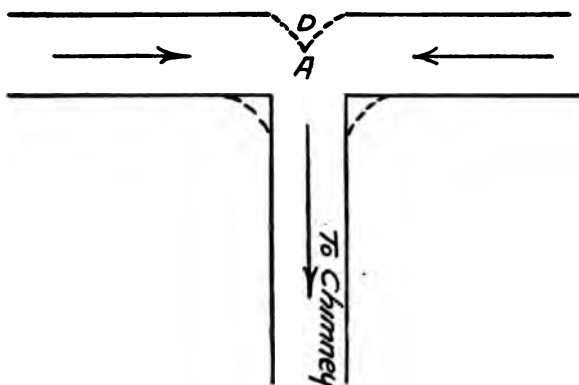


FIG. 68.

this case a construction similar to that shown in Figure 68 results. Here the gases from the two halves of the breeching meet in collision at the point A and their flow is thereby seriously restricted.

* Mr. T. A. Marsh states that a draft pressure loss of as much as 0.25 of an inch of water has been known to result from this cause. Again in this case considerable improvement will result if the corners be rounded as shown by the dotted lines in the figure. Marsh states that a curved deflector D placed in the

* Design of Breechings and Smoke Flues. T. A. Marsh, Industrial Engineering, Nov. 1912.

breeching may prove beneficial in changing the direction of flow of the gases without excessive draft loss.

A condition similar to the one just discussed arises when breechings enter a chimney on opposite sides. Here again a collision of the gases takes place and a drop in draft pressure results. Figure 69 shows a construction which is being used with success in such a case as this. AB is a baffle placed across the chimney where the breeching enters which assists in deflecting the gases in the direction of the draft. Even with this construction there must still be considerable draft loss at this point because the gases will strike this baffle almost at right angles and must lose considerable momentum thereby.

Marsh recommends a curved baffle as shown at CD in Figure 69. The shape and position of this

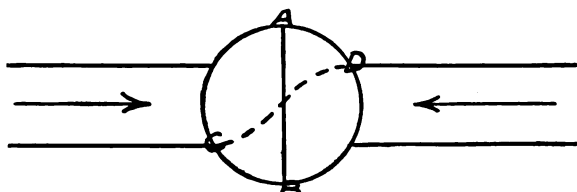


FIG. 69.

baffle is such that the gases do not meet it at right angles, but are deflected upward in a spiral path without much loss of velocity, and with only a small draft loss.

When designing a breeching the main point to be kept in mind is the fact that the furnace gases must flow through it with as little friction as possible. Anything which produces friction must be avoided so far as possible, particularly sharp bends, and places where two streams of furnace gas may meet in direct collision.

The one remaining feature of the boiler plant which has an important part to play in the combustion problem is the smoke stack or chimney. While the complete discussion of the principles entering into the design of a smoke stack does not come within the scope of this work, still a very few considerations which govern the design may be mentioned.

The sectional area of a chimney should be sufficient to carry away the furnace gases at a velocity not to exceed 25 to 30 feet per second. Since the average temperature of the chimney gases is considerably less than that of the gas in the breeching the size of the chimney can be somewhat smaller than the breeching. An average figure is to make the chimney 15 to 20% less than the combined area of breeching entering it. This provides for a reduced gas velocity in the chimney and keeps down the draft pressure loss.

The proper height for the chimney is almost entirely a question of the draft required. Draft depends upon temperature of chimney gases and on elevation above the sea level as well as upon height of chimney, but the height is the chief consideration.

The following formula may be used to calculate the height of stack required to give a certain draft.—(Stirling rule.)

$$D = 0.52 H \times P \left(\frac{1}{T} - \frac{1}{T_1} \right)$$

in which D = draft produced, in inches of water.

H = height of stack in feet above grate.

P = atmospheric pressure, pounds per square inch.

T = absolute temperature of atmosphere, degrees F.

T₁ = absolute temperature of chimney gases, degrees F.

From this formula the height of stack required to give any desired draft may be calculated.

Questions and Answers.

Q. What is the connection between boiler uptake and chimney called?

A. The breeching.

Q. How large should this breeching be?

A. Large enough to carry away the furnace gases with a velocity not to exceed 35 feet per second.

Q. Give a "rule of thumb" for the size of a breeching?

A. It should be equal to $1/6$ of the grate area served.

Q. What is the best shape for the section of the breeching?

A. The section should be circular.

Q. Why?

A. Because the draft loss is less in a circular breeching than in one having any other shape of section.

Q. How is a draft affected by a right-angle bend in a breeching?

A. There is a loss of about 0.05 of an inch for each bend.

Q. Is there any draft loss due to friction?

A. Yes, about 0.1 of an inch per 100 feet of straight breeching.

Q. How may the draft loss due to bends be reduced?

A. By using long radius bends so that the change in direction of gas flow is more gradual.

Q. When two breechings enter a stack at opposite sides, what should be done to reduce the draft loss at that point?

A. A curved baffle should be placed in the base of the stack to deflect the gases upward.

Q. What should be the section of a smoke stack?

A. About 20% less than the breeching section.

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